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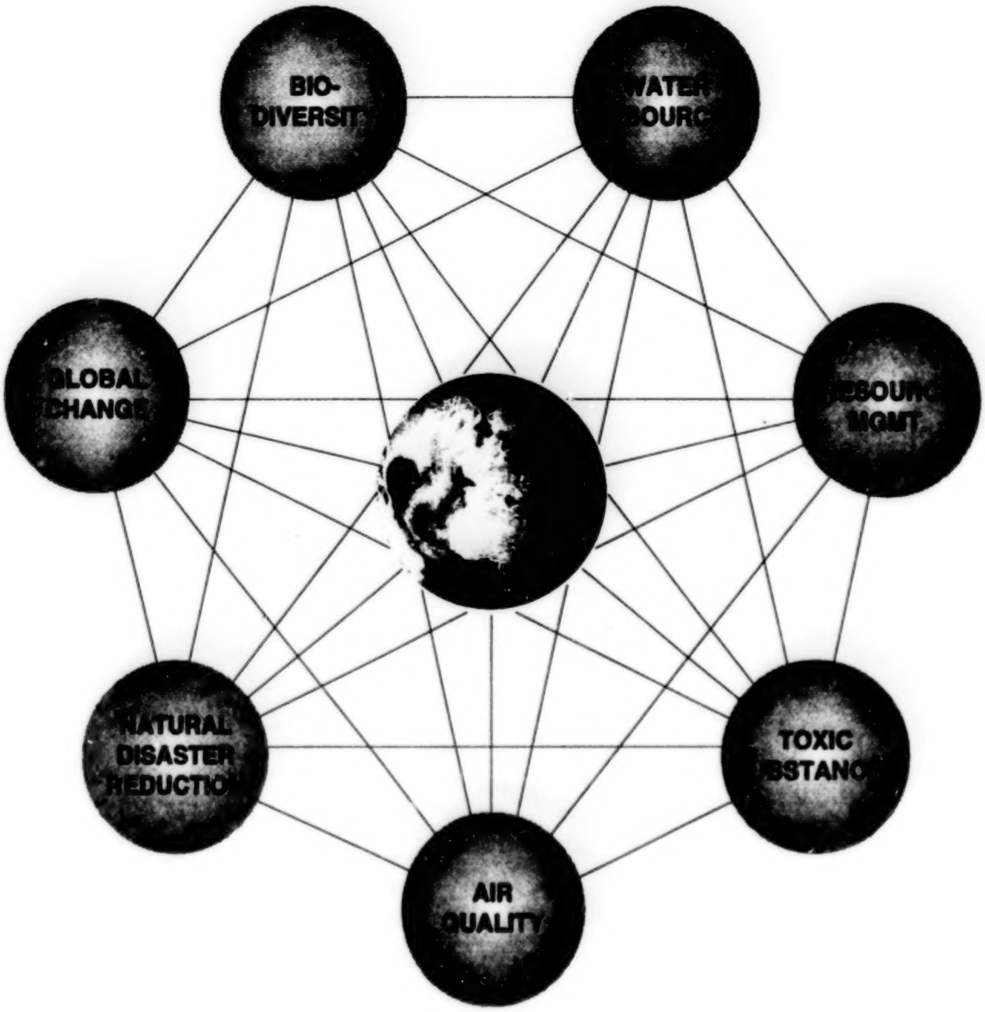
PREPARING FOR THE FUTURE THROUGH SCIENCE AND TECHNOLOGY



An Agenda for Environmental and Natural Resource Research

March 1995

NATIONAL SCIENCE & TECHNOLOGY COUNCIL
Committee on Environment & Natural Resources

97-022910

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THE WHITE HOUSE
WASHINGTON

March 10, 1995

Dear Colleague:

I am pleased to introduce the National Science and Technology Council (NSTC) 1995 Strategic Planning Documents. This document is one of nine Plans that reflect a concerted effort by each of the nine NSTC Committees, over the course of their first year, to articulate the goals, objectives, milestones, and metrics for the Federal R&D system. The Strategic Planning Documents provide a new and unique vehicle for discussing the appropriate focus of federal research efforts as well as planning for future endeavors. The public release of these documents reflects our continuing commitment to improve the Federal S&T enterprise.

It should be noted, however, that these Plans are not an end unto themselves, but rather a means to achieve national goals. Each Plan differs in approach and detail, just as each Committee has a different history, composition, and perspective; however, each Plan is central to the NSTC activities and all will be refined over time.

Since strategic planning is a continuing, evolving task, we know that we will periodically reassess and revise these documents. They must be viewed as snapshots of a dynamic, evolving process.

I hope that these materials, both individually and collectively, will form a useful foundation for a continuing dialogue within -- and beyond -- the Federal S&T enterprise.

Sincerely,

John H Gibbons

John H. Gibbons
Assistant to the President
for
Science and Technology

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Acknowledgments

The Committee on Environment and Natural Resources wishes to express sincere appreciation to the CENR Subcommittee Chairs, Executive Secretariat, Points of Contact, and Members for their participation in the formulation and review of this document. Similarly, Agency Principals and their staffs were extremely helpful in assuring that the document achieved the highest level of quality possible, within the constraints of time and resources, in presenting this strategy document for the use of agencies, research institutions, scientists and citizens interested in a Federal research agenda for environmental and natural resources research. The Committee also wishes to thank the Members of the President's Committee of Advisors for Science and Technology who reviewed this document, Drs. Murray Gell-Mann, Shirley Malcolm, Diana MacArthur, Mario Molina, and Peter Raven for their comments. Participants in the CENR Environmental Forum, and in subsequent external reviews of the various subcommittee strategy documents are appreciated for their input representing the broad community of stakeholders in environment and natural resources research. The dedicated effort of Teresa Williams, and Charlene Horak, DOE, and Janine Dolinka, NASA, in the editorial production of this document are sincerely appreciated. The contributions of the staff of the Environment Division, Office of Science and Technology Policy were essential to the preparation, review, and compilation of information included in this document.

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Executive Summary

Scientific research and technological development are critical for enhancing environmental quality, improving our nation's economy, and protecting the health of our citizens. The most challenging environmental issues facing society today range from local to regional and global, including sustainably using and managing our natural resources; maintaining biological diversity; maintaining a safe water resource; improving air quality; reducing exposure to toxic substances; limiting hazards from natural disasters (e.g., geological and weather-related hazards), understanding climate change, and minimizing ozone depletion.

Addressing these complex issues requires integration of the social and natural sciences as well as increased emphasis on areas such as developing science policy tools to improve risk assessment, and new, more cost-effective environmental technologies.

This interagency plan focuses the federal R&D dollars on our most pressing societal needs. Significant changes in the way the federal government plans and supports environmental and natural resources research and development are under way. This Administration has:

- Reinvented R&D in the federal government by creating the cabinet-level National Science and Technology Council (NSTC) to establish clear national goals for Federal science and technology investments. The NSTC, through the Committee on Environment and Natural Resources (CENR), is coordinating interagency programs among 12 agencies and is focusing environmental and natural resource R&D on those questions that most directly impact our health and our economy.
- Replaced traditional single-issue, single-agency, single-discipline problem solving with a coordinated, multiagency, interdisciplinary approach that brings together natural and social scientists, economists, engineers, and policymakers. The CENR provides clear leadership through its subcommittee structure for strategic planning, coordination, and prioritization of research and assessment objectives across all federal agencies.

R&D priorities have been developed in concert with a wide range of stakeholders from academia, industry, other private sector groups, and state and local governments. By taking full advantage of this nation's enormous scientific and technological resources, critical gaps in our understanding of important environmental issues can be identified and filled and the key issues of the future anticipated.

The CENR is strengthening the overall federal R&D program through:

- increasing emphasis on competitive awards and on peer and merit review for federally funded R&D;
- improving the links between research and policy, ensuring that research programs are anticipatory to prevent, not just mitigate, environmental threats;
- taking a leadership role in international scientific efforts by leveraging our research through international agreements and programs; and
- developing performance standards to evaluate research program effectiveness.

As a result of the process of developing strategic and implementation plans for the CENR, the following areas of research have been identified for enhanced emphasis in the research and budget planning cycles of the CENR federal agencies with environment and natural resources research:

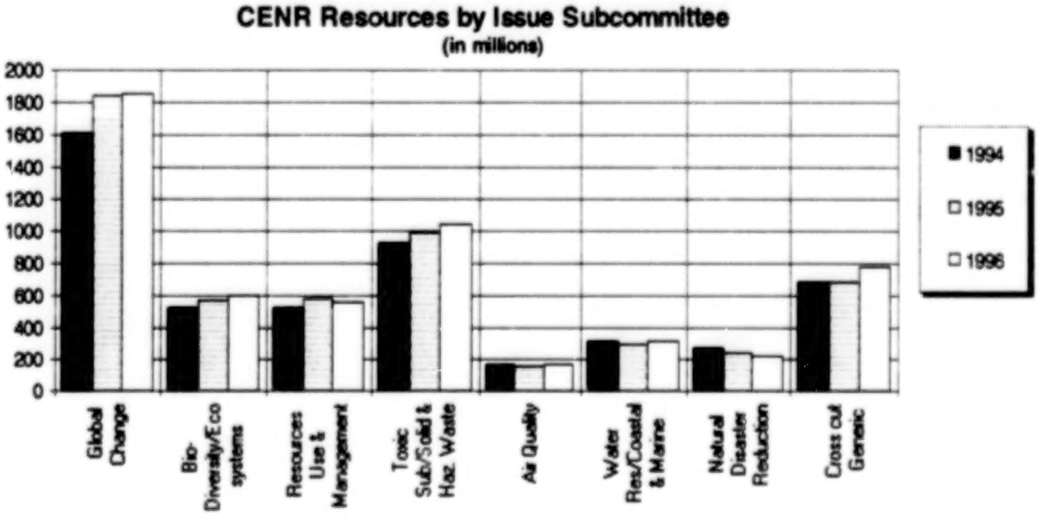
- **Ecosystem research**—to promote the efficient use of natural resources while sustaining ecosystem integrity for future generations.
- **Observations and data management**—to ensure that the necessary measurements are made efficiently and that the data are widely available to all stakeholders in easily usable forms.

Some Examples of How Investment in R&D Pays Off:

- We are saving lives through improved predictions of severe storms based on meteorological observations and models, as well as through better early warning systems.
- We are strengthening the economy by stimulating new areas in biotechnology and by commercializing new technologies in pollution prevention.
- We are protecting the health of our citizens by reducing exposure to toxic substances in air and water, and by preventing dangerous levels of ultraviolet radiation from reaching the Earth's surface by controlling chlorofluorocarbons (CFCs) and halons.

- **Socioeconomic dimensions of environmental change**—to understand the underlying human influences on the environment and the potential responses of society to change.
- **Environmental technology**—to protect the environment while stimulating economic growth and capturing emerging global markets.
- **Science policy tools**—to improve integrated assessment and risk models so policymakers can make informed decisions on complex environmental and societal issues.

The information gained from the NSTC process was used to redirect and prioritize resources in FY 1996. Twelve agencies propose $5.5 billion in environmental funding for 1996, an increase of $187 million, or 3.5%, over the 1995 level. This level of funding would allow us to place increased emphasis on the five areas identified as high-priority.


CENR Resources by Issue Subcommittee
(in millions)

Preparing for the Future Through Science and Technology: An Agenda for Environmental and Natural Resource Research is a progress report on the first stages of this evolving, multiagency, inter-disciplinary journey to reinvent how federal science agencies do business to enhance environmental quality and economic growth.

Chapter 1

Science and the Environment

Introduction

The Administration is committed to maintaining economic growth that creates jobs, protects human and ecological health, and promotes conservation of natural resources for existing and future generations. Scientific research and technological development are the *key* for sustainable economic development, that is, maintaining and enhancing environmental quality while continuing to strengthen our nation's economy and security. To reach our goals, federal investments in research and development (R&D) must be concentrated in areas where benefits will be optimized—toward our greatest challenges and where paybacks will be largest.

Sustainable Economic Development

In 1987, the World Commission on Environment and Development defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The phrase most commonly refers to courses of action that simultaneously improve human conditions and economic growth without sacrificing the health of the environment.

In 1993, President Clinton established the National Science and Technology Council (NSTC) to reinvent how R&D is conducted in the United States. The NSTC Committee on Environment and Natural Resources (CENR) is making significant changes in how the federal government plans and supports research on the environment and natural resources. We have started coordinating the previously fragmented environmental research programs across federal agencies. This approach replaces the traditional single issue, single agency, and single discipline approach to solving environmental issues with an integrated, interagency research program. This process brings together researchers and policymakers from a range of disciplines and agencies. The CENR is identifying opportunities to reduce redundancy in federal programs, fill critical gaps in research to understand important environmental issues, and anticipate environmental problems of the future and prevent them, rather than respond to them after the fact. This strategy holds the promise of unprecedented benefits from integrated planning and budgeting to reduce overlap in federal programs while solving issues in a policy-relevant and cost-effective manner.

National Goals for Science and Technology

- Improved Environmental Quality
- A Healthier, Safer America
- A Stronger Economy
- Enhanced National Security
- Improved Education and Training

National Goals for Environmental and Natural Resources Research

The range of environmental and natural resource issues related to sustainable development is diverse; it encompasses both urban and rural issues at the local and regional scales, affecting human health and the quality of both aquatic and terrestrial ecological systems. These issues include pesticides, toxic substances, hazardous and solid waste, water quality, air pollution, and natural disasters. Other important local-to-regional concerns are related to improving resource use by addressing problems such as inadequate water supplies, loss of wetlands, soil erosion, and the extraction and use of energy and mineral resources. Other critical issues have international and global implications: deforestation, loss of biological diversity, stratospheric ozone depletion, and climate change.

These issues are interrelated and are no longer the sole concern of the scientific community and environmentalists; their importance is now well recognized by the private sector and governments around the world. Sound national and international environmental policies must be based on a solid foundation of scientific, technical, social, and economic knowledge. The knowledge, developed as a result of this strategy, will enable us to meet the national goal of improved environmental quality, by providing the scientific and technical information needed to refine and couple environmental and economic policies effectively and efficiently.

In addition, the research agenda developed here will support other important national goals:

- *A healthier, safer America*, by improving our understanding of the human health implications of environmental changes and mitigating societal vulnerabilities to natural hazards.

A Healthier, Safer America

One of the highest priorities of the Administration is to protect public health and well-being. Degradation of environmental conditions can threaten health and safety. Research on the links between natural hazards, environmental change, and human health helps improve our societal response to threats such as:

- Stratospheric ozone depletion, which increases ground-level ultraviolet radiation that can increase incidences of melanoma and nonmelanoma skin cancer, eye cataracts, and immune system suppression. Research has helped to identify actions to reduce the risk of exposure.
- Changes in climate (e.g., temperature and precipitation) can increase the loss of life from heat-related mortality and severe storms and increase the range of diseases such as malaria, dengue fever, and cholera. Research can help anticipate areas where action is needed.
- Increases in urban and rural ozone and particles can increase the incidence of respiratory ailments such as asthma. Research is helping define more effective, cost-efficient control strategies.
- Natural hazards such as earthquakes and severe storms often lead to injuries and the loss of life. More advanced warning is possible through geological and meteorological research.
- Reduced exposures to toxic materials can lower the risk of health problems including cancer, disruption of the endocrine system and birth defects.
- New, more adequate safeguards in processing and storage of food can help meet minimum nutritional needs, while fewer storage and transportation losses can lead to decreased food prices.

Environmental research has contributed significantly to public health in recent years and is expected to yield additional health benefits. A better understanding of the natural world and how human activities influence it are essential to safeguard life from natural hazards and human-induced environmental changes. Research can lead to cost-effective environmental improvements and an enhanced ability to prevent or mitigate adverse health effects. New technologies can aid in cleaning up the problems of the past and preventing future problems (see Chaps. 3 and 4).

- *A stronger economy,* through the continued development of cost-effective pollution prevention technologies and a reduction of market and government inefficiencies that prevent the diffusion of environmental technologies.

A Stronger Economy: Economic Benefits of Environmental R&D

Investment in research is a prudent, cost-effective way of dealing with the nation's environmental challenges; it enables us to set management and regulatory priorities, select cost-effective strategies for action, and identify problems before they become intractable as a means to avoid costly remediation. The following are some reasons why a sustained commitment to research is "good business" for the nation.

- Scientific knowledge provides the basis for responsible decision making by government and the private sector.
- Environmental improvements translate into direct cost savings in health care through cleaner air and water.
- Reducing waste makes economic sense, saving waste management costs and avoiding indirect environmental costs.
- Environmental R&D continues to lead to new high-tech industries with high-paying jobs, while allowing us to protect the environment faster, better, and cheaper.
- Energy supply and demand R&D ensures greater national security, energy independence, and competitiveness for the U.S. economy in the future.
- Better planning for natural disasters could save countless human lives and billions of dollars per year.

- *Enhanced national security,* by providing the information needed to reduce destabilizing environmental degradation and resource distribution and depletion that can lead to economic and political destablization.

Enhanced National Security

Historically, the distribution of natural resources has been a basis for conflict between nations. Environmental degradation, ecological damage, and the depletion of natural resources can easily give rise to confrontation between nations that could lead to armed conflict. In the future, global-scale issues, such as human-induced climate change, are projected to have their greatest adverse effects in developing countries. Predicting, preventing, and/or remediating these potentially destabilizing environmental issues coupled with the development of long-term sources of food, water, and energy are essential to global security. A world in which destabilizing factors are minimized enhances our own national security.

The transfer and application of science and technology developed through federal research programs can have far-reaching effects throughout the world. Foreseeing and preventing environmental disasters will reduce our requirements for relief efforts that are expensive in terms of material, personnel, and national will. Other applications of environmental science and technology will ensure that our forces are able to deploy and operate safely and effectively on land, at sea, and in the air.

- *Improved education and training*, by developing innovative curricula and continuing education programs on the environment and natural resources with such mechanisms as government and private-sector partnerships.

Americans enjoy some of the cleanest air, land, and water in the world. For centuries we have reaped the benefits of seemingly unlimited natural resources. In recent decades, however, our understandings of natural processes, the fate of some contaminants, and the consequences of some resource use activities have evolved. For example, we now know that certain chemicals, such as heavy metals and pesticides, can build up in the environment and may cause harm to human health or ecological systems at levels far lower than ever imagined previously. We also now know that releases of seemingly harmless levels of sulfur and nitrogen air pollutants may travel great distances, affecting areas hundreds or even thousands of miles away. Some commercial fisheries, for example, experience economic loss due to over fishing, or to periodic outbreaks of disease or loss of habitat, which can be related to various forms of estuarine or ocean pollution. Some of these effects are just now being recognized after decades of progress in environmental protection. As a result, even in the United States, we have rivers that are not suitable for fishing or swimming, groundwater that we cannot drink, and urban areas where air pollution poses health risks to children, the elderly, and other more susceptible individuals.

The environment often can be restored from overuse and degradation from pollution. The challenge before us is to obtain the knowledge base to more cost effectively remediate the problems facing us today from past actions, while building the understanding of our natural resources necessary to sustainably meet the needs of society in future generations, and anticipating our vulnerability to future environmental change.

Increases in population and industrial activities during the last century are anticipated to continue into the next, and they are affecting the environment in profound and often irreversible ways. A diverse range of environmental issues faces us at all scales—local, regional, and global. Scientific and technical information is needed to make sound future policy and management decisions on issues such as maintaining world agricultural productivity, stemming the loss of biodiversity, minimizing the costs of natural disasters, and mitigating climate change.

> "We not only made wise investments in science, but we are using its results in common-sense, cost-effective ways to protect our communities, our families, our public health and our environment. Without scientific research and its application, today would be a very different day—one with fewer problems avoided, one with less healthy citizens, one with fewer thriving local economies. We would be spending far more on handling crises, and doing far less to protect our future and our children's future."
>
> *Honorable Carol M. Browner, Administrator*
> *U.S. Environmental Protection Agency*

Environmental Technology, the Key to a Healthy Economy and a Healthy Environment

Environment technologies are the bridge to a sustainable future, a bridge that, if well engineered, will facilitate the achievement of our long-term environmental, energy, and economic goals. As the engine of economic growth, technology has been responsible for as much as two-thirds of the increase in our nation's productivity since the Depression. Today, environmental technologies offer a win-win opportunity for our nation and the world as a whole: economic growth through the development and diffusion of environmental technologies will result in more jobs, and a clean environment will mean a higher standard of living for ourselves and the generations that follow.

Today, environmental issues largely focus on cleaning up pollution that is already in existence: building scrubbers that remove sulfur dioxide before it leaves a smokestack, for example, or cleaning up waste sites that are already contaminated. Increasingly, environmental technologies will instead aim at the avoidance of environmental harm altogether. Energy systems will shift toward cleaner fuels, and manufacturing firms will increasingly adopt products and processes designed from the outset to minimize the use of raw materials and the output of pollutants.

The United States has a large industry dedicated to the avoidance and solution of environmental problems—the largest in the world—with $134 billion in total estimated domestic and international revenues. Revenues for the rest of the global environmental industry are $161 billion, most of which is concentrated in Japan and Germany. It is estimated that the global market could grow to roughly $425 billion by 1997. Investment in science and technology today can enable our nation's industries to successfully compete in this emerging world market.

Research: Insurance for Economic Growth and Environmental Sustainability

Through research, we have made significant progress in learning how to manage our environment and natural resources effectively and to repair damage from past practices. Success is largely the result of scientific understanding of complex natural systems. With our growing knowledge has come recognition of vast knowledge gaps about many environmental issues and the need to develop information and data to manage future threats more effectively and efficiently. Society cannot afford to repeat the mistakes of the past that now require costly remediation.

> "There are good reasons to protect the earth . . . It's the safest and surest way to long-term profitability."
>
> *Paul Allaire (Chairman and CEO, Xerox Corporation)*

The challenge of protecting our environment and natural resource base while enhancing economic growth requires knowledge of a myriad of complex, scientific phenomena and their interrelationships. Effective and efficient natural resource management requires

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policy decisions informed by accurate information. Scientific research is needed to make informed judgments on the best use of this country's resources in the context of a global economy. Although the United States still possesses vast natural resources, as world consumption rapidly increases, we must ensure the sustained resource availability necessary for continued economic growth.

Faced with inadequate information, we often either fail to capture opportunities to avoid significant problems or overcompensate with controls and limits, possibly wasting resources on the wrong problems or responses. In contrast, balanced and informed public policy must be based upon a sound understanding of problems and potential solutions; this is an important role of federal scientific research. Research should provide unbiased knowledge relevant to critical policy questions. Research must enable us to anticipate potential problems so that we can prevent, rather than just respond to, environmental threats. Effective decisions regarding the environment and natural resources must be informed by knowledge from many fields, integrated across the natural, social, and economic sciences.

A New Strategy For Research

To meet the challenge for sound and cost-effective management of the environment and natural resources in the United States, the Administration has undertaken significant changes in how we plan and fund federal research. The traditional single agency and single discipline approach to problem solving is being replaced by a coordinated, multiagency interdisciplinary approach. Intractable multidimensional problems, such as those posed by many environmental issues, can be addressed only by bringing together natural and social scientists, economists, engineers, and policymakers. Science has often been decoupled from informed policy decisions; strengthening this connection is one of our highest priorities.

Principles of Environmental R&D

- Sound environmental and economic policies require a solid scientific and technical foundation.
- Environment and natural resource R&D should be policy relevant but not policy driven.
- Research should be anticipatory to prevent and/or mitigate serious environmental threats.
- A balanced approach to managing the environment and natural resources requires the complete integration of the social and natural sciences.

The NSTC, through the CENR, is coordinating decentralized agency programs to address environmental issues in an integrated manner. The CENR has seven issue subcommittees: Air Quality; Biodiversity and Ecosystem Dynamics; Global Change; Natural Disaster Reduction; Resource Use and Management; Toxic Substances and Hazardous and Solid Waste; and Water Resources and Coastal and Marine Environments. These subcommittees coordinate the federal agency programs within their particular environmental area. In addition, there are three crosscutting methodological issue subcommittees: Environmental Technology, Social and Economic Sciences, and Risk Assessment and two working groups: Observations and Data Management and Ecosystem Research. Coordination within these subcommittees will eliminate wasteful duplication and identify gaps in research.

Involving Everyone

Advice has been, and will continue to be, sought from a wide range of stakeholders from academia, industry, other private-sector groups, Congress, and state and local governments. Although the research strategy is designed to be responsive to regulatory time frames and needs, it is also designed to be anticipatory and to support long-range problem identification and solving. Federal agencies, through the CENR, are encouraged to improve the quality and effectiveness of their R&D programs by increasing the use of external peer and merit review, increasing the use of open competition to award funds, and by strengthening their extramural academic research programs where feasible. In addition, the agencies are actively seeking international cooperation in many of their programs to leverage U.S. resources, provide access to research sites worldwide, and assist in developing international scientific consensus regarding environmental and resource issues.

Critical steps in building successful R&D programs are improving education and training in all areas related to understanding our planet and providing educators at all levels, beginning with kindergarten through high school, the results of federal environmental programs in useful forms. By stimulating an early interest in science and the environment, a future generation of expertise will be assured. A special effort will be made by all agencies to obtain advice from educators on their needs and to provide useful data and information products.

The public is the ultimate policymaker. The CENR will enhance the effort to clarify environmental issues; improve dialogue on risks, costs, and benefits; and account for the effectiveness of public decisions regarding the well-being of our citizens.

Sound policies are crafted from a sound scientific base, and a sound scientific base is a product of scientific debate and consensus building. We are developing the infrastructure to involve experts from all stakeholder groups in conducting broad and credible national scientific and technical assessments of the state of knowledge. These national assessments will complement international assessments, (e.g., those conducted under the auspices of the United Nations Environment Program and the World Meteorological Organization) that are currently in place for global environmental issues such as stratospheric ozone depletion, climate change, and loss of biological diversity. It is imperative that a consensus be developed that explicitly acknowledges what is known, what is unknown, and what is uncertain. The consensus understanding can then be used to project the implications of alternative policy options and to involve stakeholders and policymakers in understanding the basis and uncertainties of those projections.

The CENR R&D strategy builds on the Administration's commitment to world leadership in basic science, mathematics, and engineering and uses advances in information technology to coordinate the large numbers of relevant information management systems currently available. In particular, the National Information Infrastructure (NII) initiative will enhance the availability of information to society as a whole. The strength of the U.S. scientific community in academia, industry, and the federal laboratories must be harnessed to obtain the scientific and technical understanding needed to realize the vision of sustainable development. The NII is an essential tool to empower citizens, businesses, and research institutions with information (the NII will also help us achieve greater research efficiencies through the efficient distribution of information).

The CENR Strategy

The CENR strategy is to provide a comprehensive, broad-based research and development program that addresses current important issues by providing knowledge and understanding which create economic opportunity, and protect the environment and health of our citizens today and in the future. Chapter 2 of this report discusses the strategy behind the reinvention of federal environmental R&D, Chapter 3 introduces CENR strategic planning in each of the critical issue areas, and Chapter 4 describes how areas that crosscut this more traditional issue-oriented approach to research are being strategically coordinated to maximize both cost and information efficiency.

The R&D priorities in this strategy address the critical gaps in scientific knowledge about the most important environmental issues of our day and provide the information necessary to anticipate issues of the future. R&D activities outlined in this strategy are designed to provide the information required for more responsible natural resource stewardship; more accurate environmental risk assessment; more cost-effective risk management; and innovative technological solutions that can make the nation's industries more competitive, while contributing to environmental quality. Filling these needs can result in policies that will lead to a better quality of life *and* save billions of dollars in environmental management costs. A 10% savings in national environmental management costs is twice the current annual level of federal R&D expenditures for environmental research. When viewed in this context, the nation cannot afford *not* to invest in the insurance afforded by a sound environmental research strategy and its implementation.

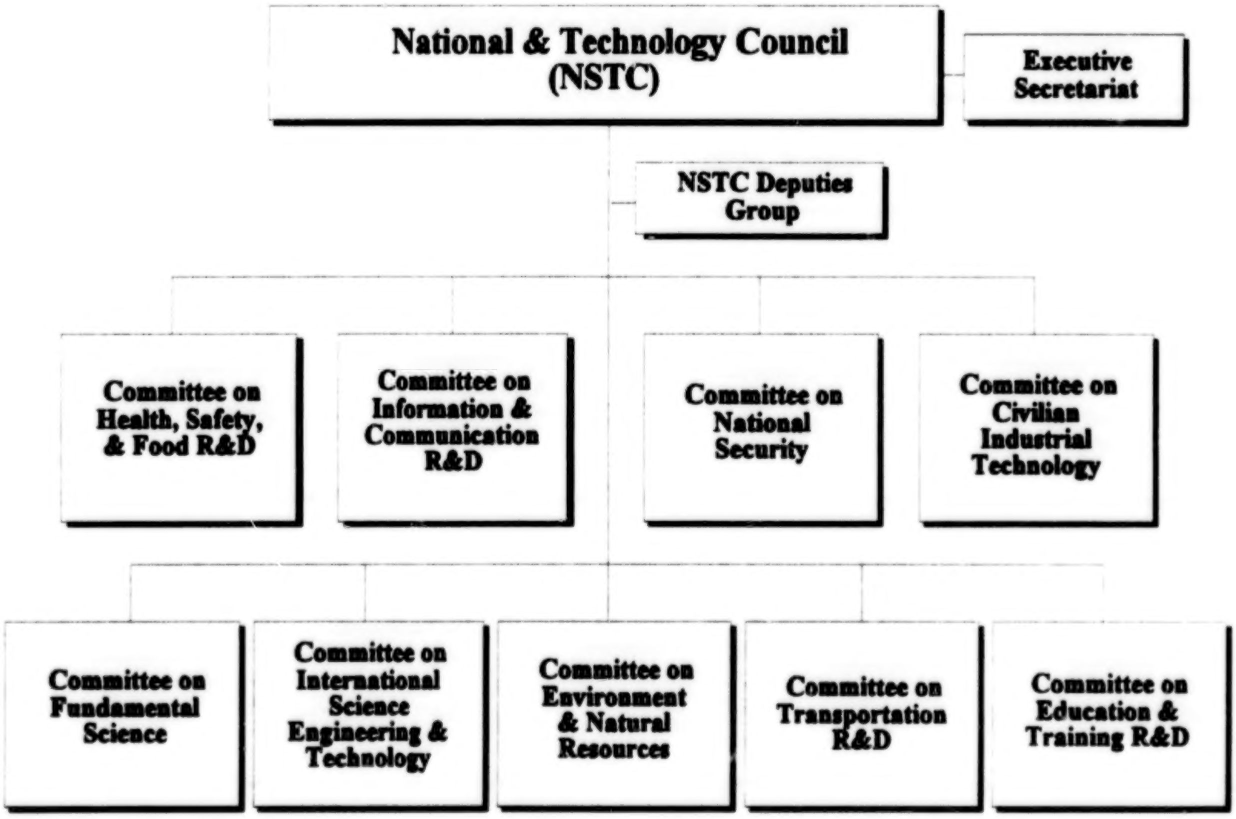
Chapter 2

Strategic Planning and Coordination of Environmental Research and Development

An important objective of the federal government is the establishment of clear national goals for science and technology investments across the government. Today's problems demand contributions from different fields of study and a team approach from the federal research and development (R&D) agencies as a means to provide an interagency strategic management system to coordinate and enhance the ability to achieve interdisciplinary solutions. President Clinton established the National Science and Technology Council (NSTC) by executive order in November 1993.

The National Science and Technology Council

The NSTC is a standing, cabinet-level body chaired by the President and composed of the Vice President, the Assistant to the President for Science and Technology, the cabinet secretaries and agency heads with responsibilities for significant science and technology programs, and other White House officials. The principal purposes of the NSTC are to (1) define clear national goals for federal science and technology investments and (2) ensure that science, space, and technology policies and programs contribute effectively to the national goals.

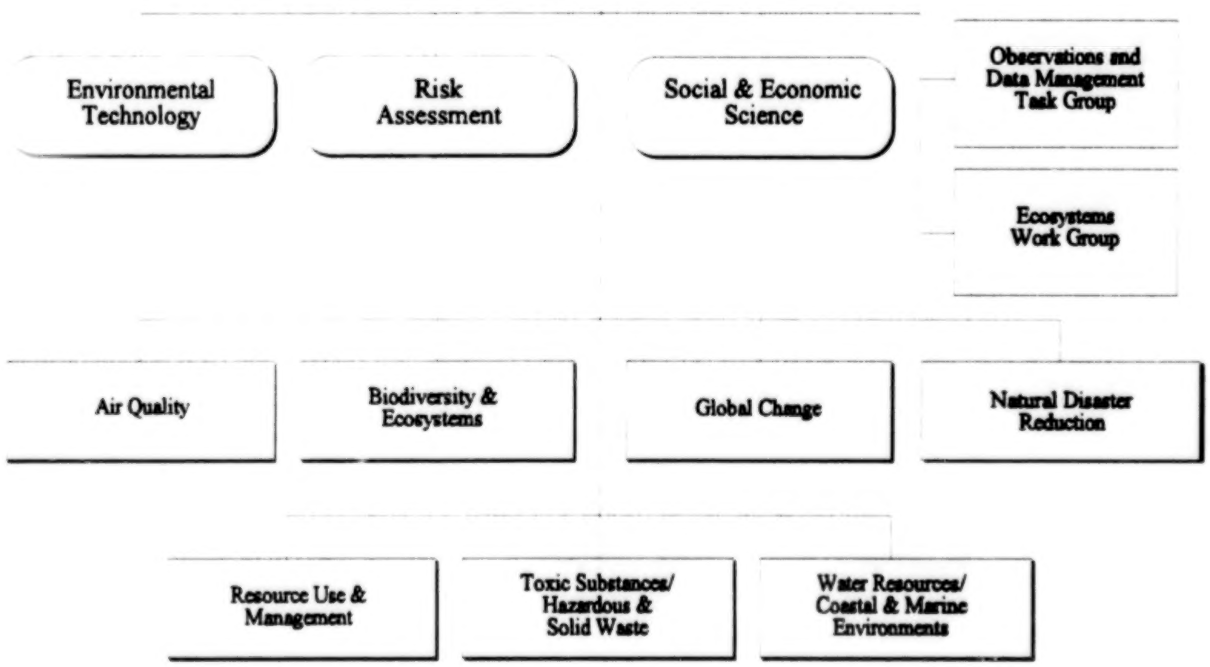

National & Technology Council (NSTC)
Executive Secretariat
NSTC Deputies Group
Committee on Health, Safety, & Food R&D
Committee on Information & Communication R&D
Committee on National Security
Committee on Civilian Industrial Technology
Committee on Fundamental Science
Committee on International Science Engineering & Technology
Committee on Environment & Natural Resources
Committee on Transportation R&D
Committee on Education & Training R&D

In 1994, NSTC committees identified R&D priorities, and the NSTC, through the Office of Science and Technology Policy and the Office of Management and Budget, provided federal agencies with coordinated budget guidance for R&D. This guidance articulated FY 1996 R&D priorities that were identified by the NSTC committees and was intended to facilitate planning, coordination, and communication among federal agencies and to direct agency programs toward these priorities. This guidance was used by the Office of Management and Budget to evaluate individual agency budget submissions.

The Committee on Environment and Natural Resources

In recent years, there have been a number of thoughtful criticisms of the way the federal government has historically conducted environmental R&D. The piecemeal, single issue by single issue, agency by agency research programs once thought to be adequate to deal with the environment have been widely recognized as inadequate to deal with the complex air, land, sea, economic, and social issues associated with regional, national, and global concerns such as ocean transport of pollutants, atmospheric deposition, climate change and ozone-layer depletion, biodiversity, and sustainable development. Ensuring economic development in concert with environmental protection makes the need for stronger integration of social, economic, and environmental sciences critical as all stakeholders are drawn into the process of environmental decision making. The NSTC Committee on Environment and Natural Resources (CENR) was created as a new way to conduct coordinated, cost-effective, interdisciplinary research to address the important environmental issues of our time.

National Science and Technology Council
Committee on Environment and Natural Resources
Executive Committee


Environmental Technology
Risk Assessment
Social & Economic Science
Observations and Data Management Task Group
Ecosystems Work Group
Air Quality
Biodiversity & Ecosystems
Global Change
Natural Disaster Reduction
Resource Use & Management
Toxic Substances/ Hazardous & Solid Waste
Water Resources/ Coastal & Marine Environments

//

Major criticisms raised by independent evaluations of the federal government's environmental research structure[1]

- *No clear leadership.*
- *Inadequate links between research and policy and inadequate mechanisms for assessing the state of knowledge.*
- *No comprehensive national environmental research plan that looks beyond near-term regulatory or management needs.*
- *Imbalance between intramural and extramural R&D.*
- *Lack of funding for ecological and social sciences and for finding engineering solutions to environmental problems.*
- *Insufficient attention to long-term monitoring, data collection and management, and interpretation.*

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[1] The Carnegie Commission on Science, Technology, and Government, December 1992: *Environmental Research and Development: Strengthening the Federal Infrastructure*; National Commission on the Environment, 1993: *Choosing a Sustainable Future*; National Research Council, 1993: *Research to Protect, Restore, and Manage the Environment*; Committee for the National Institute for the Environment, 1993: *A Proposal for a National Institute for the Environment: Need, Rationale, and Structure*; Office of Technology Assessment, October 1993: *Preparing for an Uncertain Climate*; U.S. Environmental Protection Agency, 1992: *Safeguarding the Future: Credible Science, Credible Decisions*; National Research Council, 1993: *A Biological Survey for the Nation*; and the National Research Council, 1991: *Rethinking the Ozone Problem in Urban and Regional Air Pollution*.

The CENR provides clear leadership, through its subcommittee structure, for strategic planning, coordination, and prioritization of research and assessment objectives across all federal agencies. By establishing a committee structure with science and policy cochairs, mechanisms have been put in place to integrate the state of knowledge regarding environmental and natural resource issues with policy planning, and conversely, to ensure that research strategies are policy relevant. Through this document, and the supporting subcommittee strategic and implementation plans, the CENR has developed a comprehensive, national plan for environmental and natural resource research that focuses on a long-term research strategy, as well as the near-term development of understanding to support policy decisions. Through the planning activities of the issue and crosscutting subcommittees, enhanced emphasis has been placed on ecological research to (1) understand the potential consequences of long-term environmental change and (2) to promote the efficient use of natural resources while sustaining ecosystems for future generations. Similarly, increased emphasis has been placed on the integration of social sciences and assessment end points into research planning in all of the CENR issue areas. Efforts are being made throughout the CENR, with coordination by the Task Group on Observations and Data Management, to increase the efficiency with which the vast array of monitoring and other forms of data generated within the federal system are available. This process will help to better define where true gaps in long-term monitoring exist that need to be filled. The CENR has begun a process to evaluate the balance between intramural and extramural R&D in the overall mix of federal R&D. Important roles exist for federal laboratories, national laboratories (government owned, contractor operated), universities, and private industry research activities. The process of strategic planning recognizes that each of these sectors has capabilities and resources that are integral to a balanced federal research program and will strive over the long term to take advantage of the diversity of strengths afforded by each.

The mission of the CENR is to develop and implement a comprehensive strategy for environmental R&D activities across the federal government to ensure that federal R&D efforts provide the scientific and technical information needed by policy and decision makers. The organizational structure of the CENR includes full-committee and subcommittee policy vice chairs who bring high-level policy perspectives to the CENR.

The CENR consists of seven issue subcommittees created because they represent areas of important policy that transcend the interest of a single agency: Global Change; Biodiversity and Ecosystem Dynamics; Resource Use and Management; Water Resources and Coastal and Marine Environments; Air Quality; Toxic Substances and Hazardous and Solid Waste; and Natural Disaster Reduction.

The CENR has three crosscutting subcommittees: Risk Assessment, Social and Economic Sciences, and Environmental Technology (a joint subcommittee of CENR and the NSTC Committee on Civilian and Industrial Technology). The crosscutting subcommittees focus on themes common to the areas covered by the seven issue subcommittees and provide an additional mechanism for interagency coordination. Risk assessment, for example, plays an important role in issues such as the effects of toxic substances, biodiversity, loss of ecosystem integrity, natural disaster reduction, and effects of global change on human health and ecosystem function. Social and economic sciences are critical to evaluating the impacts of human activities on local, regional, and global environments and human responses to natural disasters and environmental change. Environmental technologies can help achieve the goals of several of the issue subcommittees. For example, new technologies that can provide cost- effective remediation of hazardous waste sites are of critical interest to the subcommittees on toxic substances, water resources, and resource use and management. The Task Force on Observations and Data Management coordinates requirements and capabilities in these areas across the CENR research issues. The Ecosystem Working Group provides a focus for ecosystem research coordination across the CENR issue areas.

Each CENR subcommittee is charged with defining critical policy questions or issues relevant to their issue or methodological area (e.g., risk assessment, social and economic sciences). The scientific knowledge and corresponding research necessary to meet those policy challenges are then identified, and an interagency implementation plan is developed. In order to review and guide the priority-setting process, more than 200 individuals reviewed subcommittee strategy documents at a national conference and many hundreds of additional reviewers in subsequent review workshops and mail reviews. Reviewers consisted of nonfederal scientists from academia, industry, environmental organizations, congressional staff, and the representatives of state and local governments.

Priority Crosscutting Areas for Environmental R&D

- Ecosystem Research
- Observations and Data Management
- Human Dimensions of Environmental Change
- Environmental Technology
- Science Policy Tools: Integrated Assessments and Characterizations of Risks

The CENR subcommittees include representatives from all federal agencies and accomplish government reinvention by providing opportunities for researchers and managers in different agencies to share information and coordinate research. This process, most importantly, helps identify gaps in current research and provides strategies for prioritizing new initiatives. In a period of stable to declining budgets, prioritizing research is essential to eliminate duplication and to refocus low-priority efforts. Through systematic review of R&D in each of the policy issue areas, a balanced, comprehensive program providing the scientific and technical basis for policy is being achieved. The CENR has identified five underfunded priority areas that cross all environmental R&D: (1) Ecosystem Research, (2) Observations and Data Management, (3) Socioeconomic Dimensions of Environmental Change, (4) Environmental Technology, and (5) Science Policy Tools: Integrated Assessments and Characterization of Risks. (Each of these areas are discussed in greater detail in Chapter 4.)

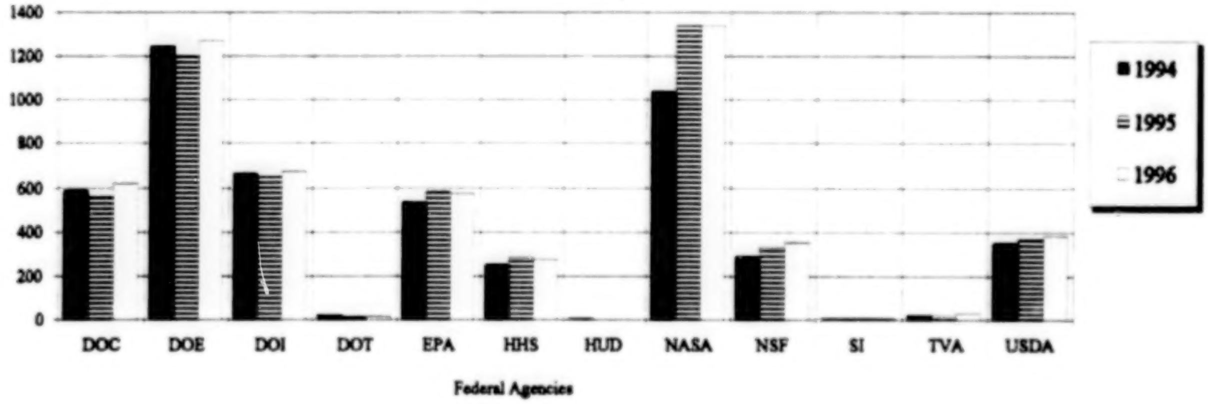
Coordinating Federal Resources

Federal investments must be used wisely for the nation. The CENR represents a new way of doing business and is an integral part of this Administration's efforts to reinvent government. The CENR has conducted an inventory and budget crosscut of environmental R&D programs within the federal agencies as a means of ensuring that the research programs maintain a balanced, fiscally responsible, and policy-relevant focus. In FY 1995, CENR programs totaled $5.3 billion; the information gained from the first year of operation as a virtual agency was used by all CENR subcommittees to develop research program budgets for the President's FY 1996 budget. The outcome of this process has been the prioritization and redirection of resources to allow modest but targeted increases in effort in the priority issue and crosscutting areas identified by the CENR:

- **Ecosystem research**—to promote efficient use of natural resources while sustaining ecosystem integrity for future generations.
- **Observations and data management**—to ensure that the necessary measurements are made efficiently and that the data are widely available to all stakeholders in easily usable forms.
- **Socioeconomic dimensions of environmental change**—to understand the underlying human influences on the environment and the potential responses of society to change.
- **Environmental technology**—to protect the environment while stimulating economic growth and capturing emerging global markets.
- **Science policy tools**—to provide the tools (e.g., integrated assessment and risk models) required by policymakers for informed decisions on complex environmental and societal issues.

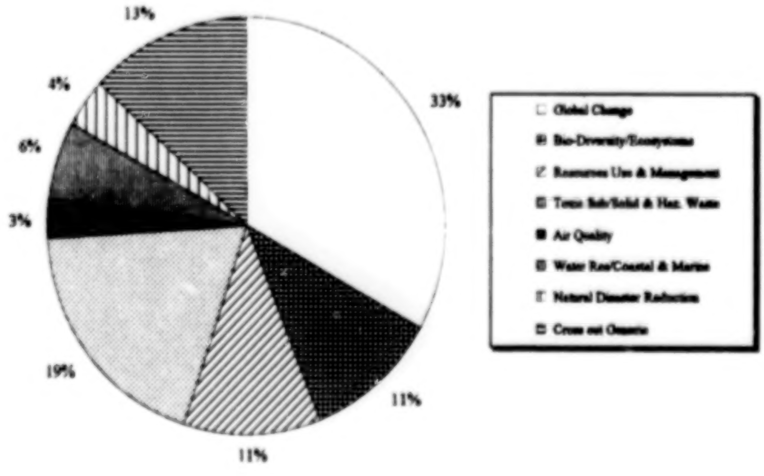
In the 1996 budget process, the agencies have taken steps in focusing their research on areas of high priority, and in coordinating their efforts. In the CENR priority areas, agencies have either redirected resources or augmented their budgets. Augmentations totalling approximately $100M and redirections of approximately $100M were distributed within the five priority areas. Further, NASA accounting changes have resulted in additions in the generic crosscut line of $88M in FY 1996 (MTPE launch costs).

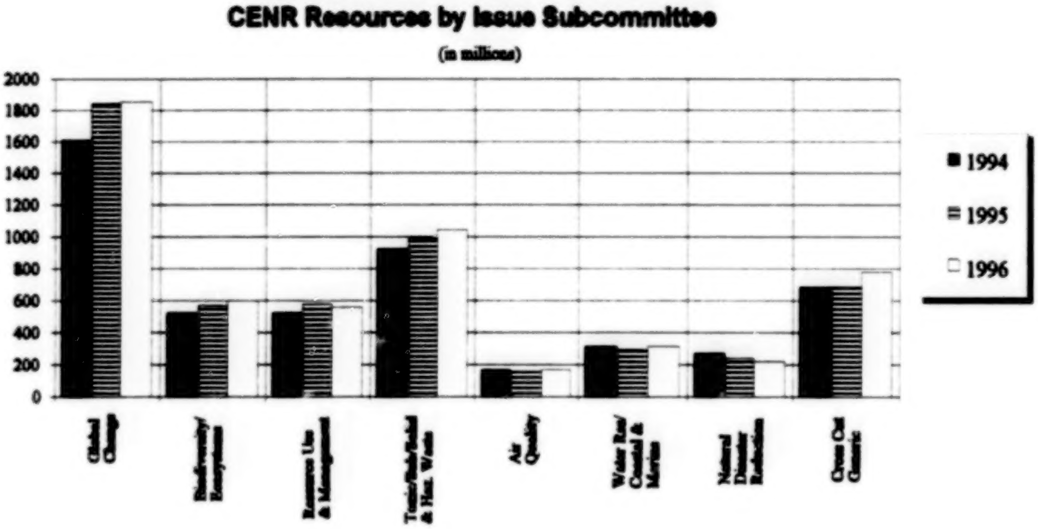
Because of the inextricable link between energy and the environment, the resource estimate for the Department of Energy reflects a conscious decision to include a major portion of the Department's energy research and development within the Committee on Environment and Natural Resources. This large and diverse portfolio of energy R&D programs is essential to meeting our national environmental goals as well as addressing global environmental concerns. Similarly, the large NASA resource estimate is dominated by the major investment in the Earth Observing System which is a critical element for future observation of the Earth's changing environment.


Federal Investments in Environment & Natural Resources R&D

(in millions)

This Administration established the CENR to develop a strategic agenda and priorities for environmental R&D across the federal agencies. The CENR will continue to establish environmental R&D priorities across the federal government and to facilitate the coordination of this research across the agencies and departments. Setting these priorities will ensure that the United States remains on the leading edge of environmental R&D and that such R&D provides a strong scientific basis for decision makers responsible for the protection, management, and stewardship of environmental systems and resources.





Improving the Process of Federal R&D in the Environment

The CENR is increasing the involvement of the academic community through merit review, peer evaluation, and the competitive selection of federal R&D projects.

The Administration is evaluating the balance between extramural and intramural R&D programs in the federal environmental R&D system. The Administration has asked all federal agencies to take a careful look at the balance between intramural and extramural environmental R&D activities within their agencies with the goal of increasing the involvement of the academic community and the private sector by competitively selecting more R&D awards. In addition, there may be instances where the quality of the research endeavor could be strengthened by combining the intellectual and institutional capabilities of both universities and federal laboratories, thus improving the overall quality and cost effectiveness of the federal research program. An ad hoc working group of the CENR is analyzing peer review and competitive awards across all the agencies; the conclusions will be available in early 1995.

Strengthening international cooperation and collaboration on important global issues such as climate change and biodiversity is a critical way to improve the leveraging of research effort and cost. The CENR has begun a process of improved integration with relevant international programs.

Competitive Awards, Strengthened Academic Research, and Merit Review

In articulating priorities for science and technology programs, the NSTC stated a number of Administration principles for R&D activities. One of these principles is increased emphasis on competitive awards for federally funded R&D projects. Another is that most federally funded R&D be subject to merit review by scientific peers to ensure quality. The NSTC also sets goals for ensuring that our academic institutions continue to provide an adequate supply of well-trained scientists and engineers.

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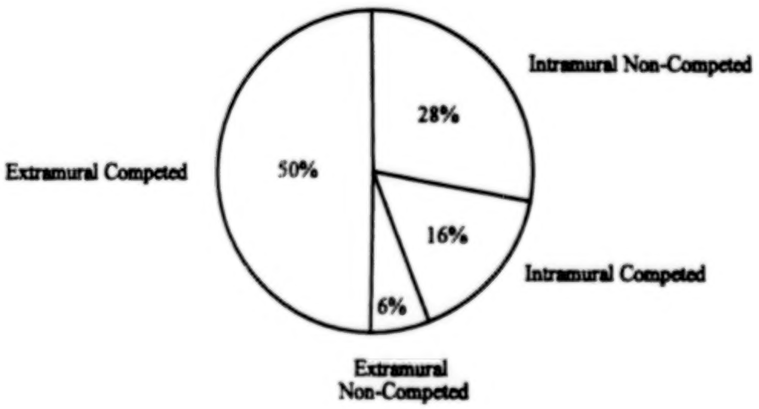
Competitive Awards

Although most in-house federal research activities funded through noncompetitive procedures are excellent and cost effective, in many cases, greater competition for funding could lead to a broader range of solutions and an overall increase in quality. Open competition allows equal access to federal research funding, providing opportunities for a greater number of scientists and institutions in federal programs. Agencies may award both internal and external expenditures competitively or noncompetitively. Competition can be full and open to attract a wide array of competitors to work on broadly defined science questions, or agencies can manage the process by limiting the array of competitors or more narrowly defining the science questions to be addressed or both.

CENR Focused Research Funding



Federal environmental science and technology programs address a diverse array of agency missions that derive from a variety of legal responsibilities, including organic acts, other authorizing legislation, directions from appropriations committees, and international agreements. Thus, some research activities and capabilities are not suited to competition. The actual requirements for in-house expertise and capability within each agency are the fundamental issues, that is, the levels of staffing and types of facilities and expertise that are essential to ensure that agencies can meet their goals and objectives and that the nation can maintain its leadership in key science and technology areas.

The CENR is assessing current competition practices. Recent advances in computers, information systems, and network technology have changed the conduct of science, facilitating research across institutional and geographic lines. As technology has advanced, the nature of environmental research has evolved as well. Larger computational power has allowed environmental R&D to develop a stronger emphasis on larger spatial scales and longer time frames, while maintaining a focus on process studies to identify cause and effect relationships. New projects and tasks commonly require more complex, often multidisciplinary analyses and strong partnerships among scientists and institutions with differing expertise. These changes heighten the need for more full and open competition with fewer barriers to enable assembly of the best research expertise and facilities.

Of the $5.1 billion reported as focused environmental R&D in FY 1994, approximately 56% was used to fund R&D efforts outside the federal agencies, most with some form of merit review prior to selection. Agencies with resource management responsibilities, such as those within the Departments of the Interior, Commerce, and Agriculture, or regulatory functions, such as the Environmental Protection Agency, accounted for the largest proportions of environmental R&D funds retained internally.

Strengthened Academic Research

Increased competitive awards for federally funded R&D are likely to attract scientists and engineers from our nation's universities and colleges. The new challenges provided by these R&D projects will enhance the ability of the United States to maintain leadership in providing the knowledge base to support sustainable development and the long-term stability of our nation's natural resource base. It is essential to ensure that our academic institutions are able to continue to provide an adequate supply of well-trained scientists and engineers, and at the same time, enhance scientific and technological literacy for all Americans. Fiscal year 1994 levels of extramural research within CENR totaled approximately $3.0 billion. In response to a national priority to strengthen competitive, high-quality extramural research, CENR agencies are reevaluating how strategically targeted, investigator-initiated research at academic institutions and competitively awarded research within mission agencies can be used to encourage cutting-edge science and technological innovation and to increase the relevance of fundamental research to the national goals as established by the NSTC. As an example of leadership in this reevaluation, the Environmental Protection Agency has committed to increase, over a period of years, the proportion of agency funds available for extramural competitive awards by approximately fivefold.

Merit Review

Regardless of whether agencies conduct R&D internally, at federally funded, contractor-operated national laboratories, or provide extramural research funds to nonfederal scientists, rigorous merit review enhances the overall quality and value of science. Merit review includes both evaluation of R&D efforts for their relevance to science and policy needs and scientific peer review of individual studies for technical soundness. Agencies are planning to tailor the review process to the size, scope, and nature of the activities being planned or assessed, while accommodating specific agency programs, priorities, and technical information needs. Although the CENR subcommittee strategies provide a link to ensure the relevance of selected science programs and goals to management and policy needs, merit review is critical in providing quality control.

Evaluating interim and final project performance is essential. These elements can be considered under the general aegis of merit review, but they are sometimes neglected under the pressure to move on to the next issue. However, if appropriate goals and milestones are established in the initial project planning, rigorously applied periodic or postperformance review can lead to better science, improved performance, and a clearer view of the next steps.

International Cooperation

Many major environmental problems we face have global implications and must be addressed internationally. These include transboundary air pollution, desertification, deforestation, marine pollution, natural disasters, loss of biological diversity, stratospheric ozone depletion, and climate change. The United States must take a leadership role on these issues to protect the world's environmental and natural resources for future generations.

Many nations, both developed and developing, contribute to this international cooperative research, primarily through three major international programs: (1) the World Climate Research Program (WCRP), (2) the International Geosphere-Biosphere Program (IGBP), and (3) the Human Dimensions of Global Environmental Change Program. These international programs are coordinated at several levels, ranging from scientist-to-scientist, to agency and government interactions. Many of these arrangements involve United Nations agencies including the World Meteorological Organization (WMO), United Nations Environment Program (UNEP), and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The International Council of Scientific Unions (ICSU) provides leadership in the planning of many of these programs, including the WCRP and IGBP. The United States shares in the funding of ICSU and supports the IGBP Task Force on Global Analysis, Interpretation, and Modeling, located at the University of New Hampshire.

The United States is a major participant in international efforts to understand and assess the state of knowledge about global environmental change. Hundreds of scientists from more than 50 countries have participated in recent assessments that have included reviews of scientific results, environmental impacts, technologies, and economic considerations. These intergovernmental assessments are especially important as they serve as primary inputs to the many international conventions and protocols that the United States supports, including the Framework Convention on Climate Change, the Montreal Protocol on Stratospheric Ozone, and the Convention on Biological Diversity.

The Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the WMO and UNEP. The IPCC produces assessments on climate change that characterize the state of knowledge within the research community. This process has been critical to establishing scientific consensus on climate change issues, largely because of the extensive involvement of a diversity of national and scientific backgrounds, representation of minority views on issues of disagreement, extensive peer review, and a commitment to scientific excellence.

The IPCC produced the 1990 assessment covering changes in climate, potential impacts, and response strategies. A 1992 update to the 1990 volume was developed for the Earth Summit in Rio de Janeiro. These documents provided the basis for the international adoption of the Framework Convention on Climate Change in 1992. A 1994 special report focuses on radiative forcing of climate resulting from human-made emissions of greenhouse gases and includes technical guidelines for evaluating sources of greenhouse gas emissions and potential impacts of climate change. With involvement of thousands of scientists from around the world, the IPCC currently is preparing a second comprehensive assessment of climate change. This set of three reports, scheduled for completion in 1995, will address the current state of knowledge of the climate system and its potential perturbations; the vulnerability of natural and socioeconomic systems; and options for avoiding, adapting to, and ameliorating climate change.

Stratospheric Ozone Depletion Assessments

The Montreal Protocol on Substances that Deplete the Ozone Layer went into effect in January 1989, and U.S. scientists have provided leadership in developing a series of international assessments for stratospheric ozone depletion. These reports have been sponsored by UNEP and the WMO, and summarize the current state of knowledge of scientific, environmental, and economic and technological matters relevant to implementation of the Montreal Protocol. Assessments in 1989 and 1991 served as the basis for amendments to the Montreal Protocol that were adopted in 1990 and 1992. A 1992 supplementary assessment on the science, technology, and economics of methyl bromide were the basis for decisions made that year to limit methyl bromide use. With the involvement of many of the world research community, the Assessment Panels of the Montreal Protocol are completing a set of reports, available in early 1995, on the state of understanding of ozone-layer science, the effects of ultraviolet radiation, and the technical and economic options regarding the use of ozone-depleting substances and their substitutes.

The Global Biodiversity Assessment

The Global Biodiversity Assessment was approved by UNEP for Global Environment Facility funding in May 1993. The objective is to provide an independent, peer-reviewed analysis of current scientific issues regarding biodiversity. The analysis will address issues such as methods for characterizing species, monitoring, sustainable use of biodiversity, biotechnology, and data and information management. The assessment will examine the current state of knowledge, identify gaps in understanding, and report where scientists have reached a consensus, as well as where scientific uncertainty has conflicting views.

Chapter 3

Charting New Directions for Research

The Committee on Environment and Natural Resources (CENR) is leading the effort to coordinate all federal environmental and natural resource research and development (R&D) activities and to improve the links between the science and policy components of the executive branch. A unique aspect of the CENR is that subcommittees are organized by key environmental policy areas. This structure was created recognizing that coordinated, interdisciplinary, multiagency R&D efforts are required to respond effectively to complicated environmental problems.

The strength of the CENR, and its subcommittees, is active participation from all relevant agencies and offices of the White House, including the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB), during all phases of the budget process. The CENR is not a top-down, decision-making entity of the White House. The CENR is working because there is buy-in at all levels of the agencies, from program managers to agency heads. R&D priorities must, and will, explicitly take into account Administration priorities, environmental statutes, and international conventions. Agency agendas that are consistent with the priorities of the interagency process are likely to have highest priority in the budget process. Our recently completed 1996 budget process demonstrated that agencies responded with their budget planning to the top priorities developed across the federal government and in concert with stakeholder guidance received through the national forum and external reviews.

The CENR Challenge

The overarching policy challenge that the CENR addresses is: *how to ensure the compatibility of long-term economic growth while protecting the environment and quality of life?* For each environmental issue, the policy questions are similar:

- What are the natural phenomena and human activities that cause environmental change?
- When, where, by how much, and at what rates will the environment change as a result of human activities? Who will be most affected?
- How will natural and human systems be affected by environmental change, including extreme events?
- What are present and prospective technical options and policy responses for mitigation and restoration of, and adaptation to, environmental changes?
- What are institutional, economic, and attitudinal barriers to implementing available options, and what are the costs and benefits of implementation?

Obtaining the scientific and technical information required for policy formulation will require understanding (1) the state of the natural system and its susceptibility to changes, (2) the socioeconomic dimensions of environmental changes, (3) the human health consequences of environmental changes; and (4) the vulnerability of socioeconomic and ecological systems to environmental changes.

For the first time ever, priority issues such as biodiversity, ecosystem dynamics, resource use and management, and water resources are being fully coordinated in an interagency program. Other issues, such as global change and elements of air and water quality, have benefitted for a decade or

Relevant Environmental Policies and Legislation

To guide national policy, a number of federal laws aim to preserve environmental quality and natural resources. The United States has also entered into international agreements to address regional and global environmental issues.

Major Environmental Health and Pollution-Related U.S. Laws

- Toxic Substances Control Act
- Federal Water Pollution Control Act
- Oil Pollution Act
- Safe Drinking Water Act
- Clean Air Act
- Occupational Safety and Health Act
- Comprehensive Environmental Response Compensation, and Liability Act
- Resources Conservation and Recovery Act
- Pollution Prevention Act
- Federal Insecticide, Fungicide, and Rodenticide Act
- Public Health Service Act

Major Natural Resource Related Laws

- National Environmental Policy Act
- Endangered Species Act
- Resource Conservation Planning Act
- Forest Land Management Planning Act
- Magnuson Fisheries Conservation and Management Act
- Energy Policy Act
- Global Climate Change Protection Act
- Renewable Natural Resources Planning Act
- Coastal Zone Management Act
- Marine Protection, Research and Sanctuaries Act
- Ocean Dumping Ban Act
- Shore Protection Act
- Marine Plastics Pollution Research and Control Act
- Global Change Research Act
- Atomic Energy Act

Natural Disaster-Related U.S. Laws

- Disaster Relief Act
- National Earthquake Hazards Reduction Act
- Weather Service Modernization Act
- National Flood Insurance Act
- Flood Disaster Protection Act
- National Flood Insurance Reform Act

Regional and Global Initiatives, Agreements, or Conventions

- Convention on Long-Range Transboundary Air Pollution
- Vienna Convention to Protect the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer
- United Nations Framework Convention on Climate Change
- Convention on Biological Diversity (signed, not ratified)
- International Decade for Natural Disaster Reduction
- London Dumping Convention
- International Convention for the Prevention of Pollution from Ships
- Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (signed, not ratified)
- Global Forestry Agreement
- Agenda 21 and Follow-On Activities (e.g., United Nations Council on Sustainable Development)
- North American Free Trade Agreement
- General Agreement on Tariffs and Trade

more from interagency coordination. The segments of this chapter that follow reflect those differences in maturity as they describe the goals, current research programs, and key policies and legislation supported by research in each of the issue areas (see box on the following page). Also described are areas of enhanced research emphasis in FY 1996 and beyond, selected milestones expected in the near term (3 to 5 years), and selected examples of recent research accomplishments illustrating the importance of research in each of these important issue areas. The milestones listed are representative but are not a comprehensive listing of activities required to accomplish the goals of the program. A comprehensive listing of milestones is associated with separate strategy and implementation plans for each of the issue areas, which are also to be published.

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Air Quality

The goal of the federal air quality research program is to help protect human health and the environment from air pollution by providing the scientific and technical information needed to evaluate options for improving air quality in timely and cost-effective ways.

Research characterizes the sources of air pollution, builds a predictive understanding of the phenomena involved, quantifies the human-related effects and impacts, and assesses the state of knowledge in policy-relevant terms. The five air quality issues are: (1) ground-level ozone, its precursors, and other ambient air pollutants; (2) acidic deposition; (3) hazardous toxic air pollutants; (4) visibility and health-related airborne particles; and (5) indoor air quality.

Relevant Policies, Issues, and Legislation

- Clean Air Act Amendments (CAAA) of 1990
- Characterization of the relative risks and sources of air pollution that are not covered by comprehensive legislation or regulation, such as degraded indoor air

Current State of Understanding

Many air quality issues face legislative mandated assessments, regulatory actions, or other important policy decisions within coming years. The environmental issues pose potentially large, but often unquantified, risks to human health and well-being. At the same time, however, implementation of planned or potential control measures can have very large socioeconomic impacts. For example, the states are preparing their plans for implementation of the CAA requirements regarding urban ozone attainment, and the magnitude of the challenge is apparent. Hence, a demonstrable and defensible scientific understanding of the phenomena involved is a key input to prudent courses of action or inaction.

High levels of surface ozone are occurring in numerous urban areas and are known to have adverse health effects, particularly on more susceptible citizens. The clear cause of this urban pollution is human-generated emissions, notably from automobiles and electric power plants. Despite requirements to reduce emissions, abatement of urban ozone levels has been less than anticipated, and the full scientific explanation as to why is not in hand. Crop damage by elevated rural ozone levels is moderately well characterized, but recent research points to a need to revisit the strategies for reducing such levels. Ozone damage and growth retardation relations for forests are poorly understood, particularly from the standpoint of exposure to multiple stresses.

Similarly, sources of acidic deposition are also clearly related to human activities. Trends in wet acidic deposition are now fairly well defined and show declines over the past few years associated with emission reductions. However, the amount and changes in dry deposition are poorly characterized. Further, responses of aquatic life, forests, soils, and materials to exposure levels are not well quantified, which limits decisions regarding appropriate future emission reductions.

Several studies clearly show an association between airborne fine particles and human health, but plausible biological mechanisms linking such factors have not been identified, making it difficult to determine which aspects of particular matter (PM) could be the most harmful. Moreover, measurement techniques are expensive and crude. Certain clearly toxic compounds (e.g, lead and asbestos) are well understood and are being addressed by specific regulations. Trends in visibility in public lands show that deterioration is easily noted by the public seeking to enjoy those areas, but the sources of the pollution involved cannot always be determined.

People spend 90% of their time indoors, and the indoor levels of many pollutants, both human made (e.g., organics) and natural (e.g., radon) are often much higher than those outdoors. Qualitative association of poor health and "sick buildings" is clear to many workers. However, widespread quantitative evaluation of indoor air quality is still in its infancy, and even well-known issues such as radon still have debatable aspects, all of which limit the ability to carry out meaningful cost-benefit analyses.

Research Program

Current air quality research focuses on observing *what* is changing and understanding *why* in order to better predict environmental responses to a spectrum of possible choices that face decision makers. Important ongoing research activities that continue to receive strong emphasis include:

- *Long-term observations and analysis* to evaluate the effectiveness of recent regulatory initiatives aimed at improving urban air pollution, acid rain, and visibility in our national parks.

- *Identification of emerging health or environmental problems* associated with susceptible human populations; long-term exposures in the home or workplace; and crop, forest, and material damage, which are required to set appropriate standards and actions.

- *Characterization of the processes involved in air quality changes* to improve inventories of emissions, chemical and meteorological processes that link source and receptor areas, and the testing and improvement of predictive air quality models, all of which focus on providing scientifically defensible options for decisions.

- *Assessing the state of knowledge on understanding air quality issues*, which includes the knowns and unknowns of the science and the costs and benefits of potential actions or inaction.

Areas of Enhanced Emphasis

- ***Understanding the formation of ground-level ozone in urban and rural areas***. Elevated ozone causes considerable cost to the nation in health care and lost agricultural and forest productivity. Expanded research on the causes of ground-level ozone is needed to determine how well current regulations are meeting their objectives and to provide critical input to the "midcourse" state implementation plans of the CAAA. This information will help determine whether current and future regulatory actions reduce ground-level ozone in the most cost-effective way.

Specific activities will include: (1) field observations and networks to improve the characterization of human-made and natural sources of ozone precursors, formation and loss processes, exposure levels and impacts, and overall predictive capabilities and (2) an integrated state-of-understanding assessment of ground-level ozone, its consequences, and mitigation options. These activities will be coordinated under the new North American Research Strategy for Tropospheric Ozone (NARSTO) Program, which involves federal, state, and local agencies; Canada and Mexico; utilities and other companies; academic institutions; and private and national laboratories.

- ***Characterization of the health impacts of airborne fine particles***. Epidemiological studies indicate significant associations between fine airborne particles (PM) and adverse human health effects at PM levels below current standards. The biological mechanisms of health effects are not well understood. New methods will be developed to effectively and inexpensively measure PM concentrations to facilitate better characterization of population exposures. Additional scientific data will be collected to ensure that current and future actions are effective.

  Research is conducted to understand the risks and causal mechanisms by which particles adversely affect human health, with particular foci on exposure levels, size and chemical content, role of exposure to multiple stresses, and identification of particularly susceptible human populations.

Selected Milestones, 1995–1998

- Provide scientific input to air quality management planning for the highly stressed Great Smoky Mountains National Park by completing an extensive field study with diagnostic modeling to understand the extent, causes, and processes involved in local visibility problems.

- Characterize the roles of production and movement of ground-level ozone precursors and the role of meteorology on ozone formation in a region of high natural hydrocarbon emissions and a region of high complexity (Nashville Field Campaign-Southern Oxidants Study) to help formulate more effective emission-abatement applications for specific regions of the country.

- Quantitatively compare the effects of anthropogenic fine particles to those of coarse, windblown dust particles on human health. This information will better identify the sources that could be most effectively addressed to lower health risks.

- Conduct a National Acid Precipitation Assessment Program (NAPAP) assessment of (1) the reduction in deposition rates necessary to prevent adverse ecological effects and (2) the costs, benefits, and effectiveness of the current acid deposition control strategies mandated under Title IV of the CAAA of 1990.

- Create Great Waters and Urban Toxics Inventories to characterize the major risks faced by Native Americans from their basic fish stocks and by inner-city individuals from airborne toxics in the urban environment. These inventories will help to design impact evaluation methods and appropriate amelioration strategies.

- Conduct a comprehensive state-of-science assessment of surface-ozone that is summarized in policy-useful terms and that is prepared by the broad scientific community as well as other communities, sponsored by the relevant agencies, reviewed by peers and stakeholder communities, and timed to aid decisions associated with midcourse corrections in the state implementation plans required by the CAAA.

- Standardize indoor air tests, develop instrumentation, and evaluate standard procedures that will lead to commercialization of monitoring equipment to improve the "health" of the nation's residential and commercial buildings.

Research Successes

Preparing for the Future through Science & Technology March 1995

New Findings Refocus Ozone Management Strategies

Recent research has provided a new understanding of how the pollutant ozone is produced in rural areas. Scientists from federal agencies and universities, working together at rural sites, now better understand the differences in formation of ozone in urban and rural areas, where it can be an important factor in agricultural and forest productivity. This insight suggests that ozone could be managed differently in rural areas than in urban areas and opens more cost-effective options for risk reduction.

Ozone formation in rural areas causes a significant stress on our nation's agriculture and forest industries. For example, recent estimates suggest that a 25% reduction in ozone levels would yield increased crop production worth in excess of $2 billion per year. In addition, ozone is a significant stress to ecosystems in many of our national parks and wilderness areas. Ozone is formed from volatile organic compounds (VOCs) and nitrogen oxides in the atmosphere. In urban areas, these compounds are emitted primarily by human activities; hence, control strategies must be tied to those activities. In rural areas, however, VOCs are largely contributed by vegetation. Nitrogen oxide control strategies may therefore be the most effective in combatting high ozone levels in rural areas.

Federal, state, and local agencies are cooperating in studies to monitor and model ground-level ozone, especially in rural areas. The Clean Air Act Amendments can be formulated and implemented more effectively when we understand the processes involved, the regions of the country affected, and the effects of reducing VOC or nitrogen oxide emissions on ground-level ozone formation.

Interagency Cooperation Pays Off with Long-Term National Picture of Acidic Deposition

Since 1978, collaboration between federal agencies, state organizations, universities, public utilities, and industry has built a stable air monitoring network through the National Atmospheric Deposition Program (NADP). This program has established a record of sulfur and nitrogen emissions associated with human activities, patterns of acidic deposition, and its impacts on the natural environment. Information from NADP was a key element in the formulation of the Clean Air Act Amendments.

The NADP was created under the leadership of the State Agricultural Experiment Stations. During the 1980s, the National Acid Precipitation Assessment Program integrated its new National Trends Network with the NADP network to provide a better picture of deposition patterns. The network has documented national trends in precipitation chemistry for over 15 years and now consists of approximately 200 stations nationwide, providing an unprecedented long-term index of our nation's air quality. Time series of observations of this nature and duration are exceptionally rare in the environmental sciences.

This deposition record will continue to document "what's coming down" and will become even more valuable as the record gets longer. In combination with complementary new stations being planned for monitoring air concentrations of key pollutants, these time series will reveal "what's changing" and, perhaps more importantly, "why." With insights from regional field campaigns and more descriptive theoretical models, the United States will gain improved predictive capabilities for managing air quality.

Biodiversity and Ecosystem Dynamics

The goal of federal research on biodiversity and ecosystem dynamics is to ensure the sustainability of the ecological systems and processes that support our social needs in areas such as agriculture, forestry, fisheries, recreation, medicine, and the preservation of natural areas. However, there are many gaps in our understanding of the relationship between environmental factors and the expression of biodiversity and/or effects of global and regional change on ecosystem structure and function. Such understanding is essential to efficient and cost-effective sustainable resource use and conservation, as well as restoration of some degraded environments.

Research is conducted to provide policy-relevant information on questions such as: What is the value of biodiversity to society in terms of goods and services (including nonmarket, nonconsumptive uses) and its intrinsic value? What are the major threats to ecosystem processes and functions? How can biodiversity in ecosystems be managed in a sustainable way in a changing global environment? How are social, cultural, economic, legal, institutional, and biological factors taken into account for informed policy making and decision making?

Relevant Policies, Issues, and Legislation

- Endangered Species Act
- National Environmental Policy Act
- National Forest Management Act
- Renewable Natural Resources Act
- Renewable National Resources Research Act
- Migratory Bird Treaty Act
- National Park Service Organic Act
- Wilderness Act

Current State of Understanding

Knowledge of species and ecosystems has been primarily derived from observational data, periodic surveys, single-discipline experiments, and case studies. There is often little ability to link site-specific studies to environmental and climatic conditions or extrapolate across a wide geographic area. As such, most management information tends to be either qualitative or anecdotal. When unexpected changes occur in populations of species, causal factors often are not understood. Only recently, with the advent of remote sensing and geographic information systems, has progress been made on describing how ecosystems and species interact at the landscape and seascape scale.

The extent of species biodiversity has been best characterized for surface-dwelling terrestrial vertebrates and flowering plants, while information on subterranean, freshwater, coastal, and marine habitats remains scarce. Although we have information on the diversity of certain groups of organisms that inhabit many ecosystems of the world and have characterized many of the crucial processes and physical and chemical limits to rate-limiting functions of many ecosystems, the relationship between diversity and ecosystem functioning is poorly understood. A good deal of attention is focused on responding to the urgent needs of species that are listed as threatened and endangered. In these instances, knowledge of the habitat requirements of a specific species may be well researched; however, there remains a larger need to understand how managing an ecosystem to benefit one species will impact the many other species that also rely on that ecosystem.

Research Program

Forests, grasslands, and wetlands and their ecological processes provide many of the goods and services that are essential for society's sustainable development. Increasing pressure on our nation's ecological assets requires that we better understand the relationships between human activity and the conservation of species and ecosystems. Research is essential for constructing effective policies that ensure the integrity of our nation's ecological systems, while avoiding unnecessary regulations. Major issues associated with biodiversity and ecosystem dynamics are addressed in studies of:

- *Biophysical requirements* needed to sustain numerous species of plants and animals.

- *The effects of existing and new resource management methods* on biological diversity, ecosystem composition, and key ecological processes, such as nutrient cycling, within both terrestrial and aquatic ecosystems.

- *Interactions among populations of species*, especially the effect of exotic species on native populations.

- *The role of species as indicators* of ecosystem status and the relationship of species to ecosystems at various spatial scales.

- *The effects of landscape fragmentation* on ecosystems, species, and processes.

Areas of Enhanced Emphasis

- ***Prepare a comprehensive map of U.S. ecosystems***. We need to know the spatial location, ecological status, and trends of major ecosystems over time. Research will couple remote sensing with ground-based data to prepare a set of ecosystem maps of the United States. The maps will include information on primary vegetation type and quality, associated plant and animal species, and current usage. This information would allow resource managers, land- and water-use planners, and policymakers to make better informed decisions at local and regional scales.

- ***Enhance access to information on the nation's plants and animals.*** Existing collections of data for millions of specimens will be computerized and made more accessible to the nation's scientists and the public. Efforts to describe additional biota and their ecological situations will be augmented. Increased information on poorly known taxonomic groups, such as aquatic invertebrates and subterranean fauna, that includes data on their geographical occurrence and associated environment conditions would greatly increase the ability to sustain terrestrial and aquatic ecosystems and to conserve biodiversity in harmony with land use.

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- ***Improve understanding of the socioeconomic values of ecosystems***. Society's well-being, including such diverse things as clean water, medicines, food, fiber, and recreation, depends on biological resources and ecological processes. The many demands placed on ecosystems require an improved understanding of the social and economic values of these ecosystems. Efforts are being expanded to understand how social and economic forces interact with biodiversity and ecosystems. This information will facilitate the conservation and sustainable use of essential ecosystem components and processes.

- ***Improve understanding of the role of species in ecosystems***. The integrity of a given ecosystem may depend in large part on the functional roles played by key plant and animal species. However, the veracity of this statement remains largely unknown. Nor is it known if there is functional redundancy among species within an ecosystem or if a key species has a significant impact on an ecosystem. Efforts are being expanded to understand the relationship between a species and ecosystem function. This knowledge is needed to adequately monitor and manage ecosystems, while avoiding intractable resource-use conflicts.

The National Biological Service

The Clinton/Gore Administration created the National Biological Service (NBS) to provide accurate biological information to support decision making about the use, management, and protection of the nation's natural resources. The NBS consists of biological research programs formerly managed by the U.S. Fish and Wildlife Service, National Park Service, Bureau of Land Management, Minerals Management Service, and other agencies in the Department of the Interior. The NBS collaborates closely with those agencies at all levels, providing a new, cost-effective, and more integrated science. Integration under the NBS enhances scientific support for policy decisions by providing a critical mass of scientific expertise; strengthening competitive peer review; coordinating resources; and reducing redundancies in multiple agencies.

In both government and the private sector, managers are frustrated by the lack of solid science upon which to base decisions. Disagreements over basic questions such as *"Are some species declining?"* and *"What are the likely effects of some action?"* frustrate discussion of problems and their solutions. In addition, the perception that facts are manipulated to support a desired outcome reduces the credibility of both government and private scientists. The NBS was created as an independent bureau to ensure that the science used in regulatory and management decisions is sound, unbiased, and available to everyone. NBS has no regulatory or resource management responsibilities, so its scientific results will not be influenced by biases for or against specific policies. NBS's job is simply to provide better science.

Selected Milestones 1995—1998

- Publish common standards and protocols needed to classify and map ecological units and their biological and physical attributes. This information will help both public and private land owners to understand how to sustainably use terrestrial and aquatic resources.

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- Publish an ecosystem map for the United States at a scale that allows land-use planners, resource managers, industry, the public, and policymakers to incorporate spatially explicit social, economic, and environmental factors into urban planning and resource management decisions.

- Complete establishment of a network of representative long-term sites to determine ecological baselines and to demonstrate how various ecosystem management approaches can be achieved. The management demonstrations will be coupled to a comparative ecosystem research program and to the development of statistically valid monitoring protocols. These links will provide a continuous flow of information to adjust resource management strategies over time to meet evolving social goals.

- Calculate the social and economic impacts (local, regional, and national) of alternative management scenarios: track cumulative social and economic effects of various ecosystem management regimes, such as impacts on fishery management and agricultural programs. Such analyses will provide policymakers with a better understanding of the social and economic costs associated with various natural resource management or protection options.

- Determine the functional characteristics to be used to group species so that data essential to successfully maintaining or restoring the population of a species can be extrapolated from studies of a few representative species to entire groups of species. These characteristics will enable extensive existing basic research on targeted key species to be used to generalize habitat requirements necessary to maintain viable populations of most species. This approach is a cost-effective way for society to avoid the need for detailed individual studies on large numbers of species.

Research Successes

Preparing for the Future through Science & Technology March 1995

The Eagle Has Landed

In 1963 the total population of American Bald Eagles had dwindled to an estimated 800 birds in the lower 48 states. Research identified the primary cause as DDT and other forms of organophosphate used in insecticides. Research was begun to understand the ecological needs of this species and to devise methodology for captive breeding and reintroduction. Today the population has risen to an estimated 8000 birds and on June 30, 1994 the American Bald Eagle was removed from the list of animal species hovering at the brink of extinction.

This delisting represented a pivotal success for the eagle and the 1973 Endangered Species Act. While the recovery of American Bald Eagle population represents the culmination of research on one species, the lessons learned from these studies translate into general principles that can now be applied to understanding how to maintain populations of many different species. Research has lead to successfully removing other species from the endangered species list including the Pacific grey whale, the peregrine falcon, the grizzly bear, the eastern timber wolf, the whooping crane, the Columbian white-tailed deer and the cutthroat trout.

Natural Wonder Opens Door to Biotechnology

One of the most significant discoveries of the burgeoning field of biotechnology derives from scientific understanding of a humble, heat-resistant bacterium that occurs naturally in the waters of the hot springs of Yellowstone National Park. Basic biological research, including systematic biology (which describes different organisms and their relationships to one another), led to the identification of the heat-resistant bacterium *thermus aquaticus* as a possible source of a heat-resistant enzyme for use in molecular biology research.

The 1993 Nobel Prize for Chemistry honored the conception of the polymerase chain reaction using this heat-resistant enzyme to make it possible to multiply a minute amount of genetic material millions of times within hours. This technique has become fundamental to diagnostic medicine, the human genome project, and forensic medicine. It also has contributed to the field of biotechnology, annually generating billions of dollars in economic activity. This is a premier example of the ability to generate wealth from biodiversity at the level of the molecule.

Global Change

The goal of global change research is to observe and document global environmental changes and identify their causes, predict the responses of the earth system, determine the ecological and socioeconomic consequences of these changes, and identify strategies for adaptation and mitigation that will most benefit society and the environment.

Research is being conducted to understand major global environmental issues such as: (1) climate change resulting from human-induced enhancement of the greenhouse effect; (2) depletion of the stratospheric ozone layer; (3) disruptive seasonal and interannual variations in temperature and precipitation, such as the El Nino-southern oscillation; and (4) large-scale changes in land use and land cover.

Relevant Policies, Issues, and Legislation

- Framework Convention on Climate Change and the U.S. Climate Change Action Plan
- Montreal Protocol on Substances that Deplete the Ozone Layer
- U.S. Clean Air Act Amendments
- Conventions related to global environmental issues such as forestry, desertification, protection of oceans, and biodiversity

Current State of Understanding

The earth's climatic, ecological, and biogeochemical record provides the context for understanding anthropogenic effects on the earth system. Over its few billion year history, the earth's geography, climate, and ecosystems have all gone through dramatic changes and fluctuations on time scales that vary from less than a decade to millions of years. Superimposed on these longer-term changes are natural fluctuations that lead to individual seasons, years, and decades with climate conditions that may differ sharply from multidecadal or centennial averages. Although global average conditions change relatively slowly, significant intra-annual and interannual to decadal variations can occur at regional (subcontinental) scales, driven to varying extent by changes in sea surface temperature and ocean circulation patterns, volcanic eruptions, soil moisture anomalies, sea ice extensions and retreats, and variations in the amount of solar radiation reaching the earth.

Since the beginning of the industrial era, atmospheric abundances of greenhouse gases have increased as a result of human activity (e.g., carbon dioxide has increased 30%), causing an increase in the radiative forcing of the earth's atmosphere. A significant fraction of this increase may have been offset by cooling associated with simultaneous increases in atmospheric sulfate and carbonaceous aerosols or by the effects of stratospheric ozone depletion. The quantitative regional and global impact of these changes on the earth's climate are strongly regionally dependent, and large uncertainties remain. Global mean surface temperatures have increased by about 0.5°C over the past century, although precipitation averaged over the world's land masses shows little or no change. However, in the contiguous United States, mean precipitation has increased by about 5%, confined to autumn. The frequency of extreme rainfall events has increased throughout much of the country. The limited set of measurements around the world, however, does not yet allow the cause (i.e., human activities or natural variability) of the small, but potentially important, changes in climate to be established.

The most important and well-defined human effects on stratospheric ozone concentrations to date have occurred through chemical changes in the stratosphere caused by increases in emissions of chlorofluorocarbons (CFCs) and other halons. The resulting stratospheric ozone depletion increases the clear-sky flux of ultraviolet (UV) radiation reaching the surface, which has been shown in field and laboratory studies to have significant harmful effects on human health and ecosystems.

Changes in land use and land cover and the resulting losses of productivity of terrestrial ecosystems are occurring on a global scale. Land-use change may lead to the depletion of localized resources of common value to social systems and have consequences that extend to the entire international community. Transformation of land from native forest cover to agriculture, grasslands, and urban development can alter the albedo and natural water cycle and result in the degradation of formally productive land and the loss of biodiversity.

Research Program

Current global change research is focused on understanding how the earth system functions, how human activities can perturb the global environment, and the consequences of such perturbations on human health, societal support systems, natural ecosystems, and the capacity of the earth system to both sustain the natural environment and meet societal needs. Recent emphasis includes both ecological and socioeconomic impacts. Important ongoing activities that continue to be priorities include:

Climate change and greenhouse effect research to (1) observe and document the extent to which human activities influence long-term climate change; (2) improve the input to and the capability of climate system models to represent relevant processes and better predict global and regional changes in climate; (3) predict the consequences of climate change on natural and socioeconomic systems; and (4) support integrated assessments of climate change, including research on the feasibility, effectiveness, and costs (market and nonmarket) of implementing response options.

Stratospheric ozone and UV effects research to (1) support international space- and surface-based observation programs to document the response of stratospheric ozone to changes in atmospheric composition; (2) develop a network to monitor surface UV radiation; (3) observe, predict, and understand the consequences to ecosystems, agriculture, and human health of long-term changes in UV radiation; (4) evaluate new and substitute compounds for their effects on the ozone layer, the environment, and human health; and (5) evaluate the role of subsonic and supersonic aircraft for their effects on stratospheric ozone.

Seasonal to interannual climate fluctuations research to (1) expand and maintain global ocean observing systems; (2) develop modeling capabilities for forecasting seasonal to interannual climate fluctuations and the expectation of unusual and extreme events; and (3) encourage multilateral collaboration in the establishment of regional application centers for using forecasts to reduce disruptive consequences of extreme climate events.

Large-scale ecosystem productivity research to (1) map global productivity of terrestrial, freshwater, and marine ecosystems using remotely sensed data (such as that from past and continuing Landsat observations); (2) determine the results of changes in land cover, desertification, and deforestation on ecosystem vitality, carbon storage and release, and the cycling of soil nutrients; and (3) conduct studies to understand the socioeconomic causes and implications of land-use change.

Areas of Enhanced Emphasis

- ***Evaluating the socioeconomic driving forces of global change.*** While human activities, such as agricultural practices, energy production, and land use, are recognized as important factors driving global environmental change, there is currently very limited understanding of the quantitative links between the two. Social sciences and economics research is needed for understanding issues such as: (1) the demographic and social factors relevant for assessing the interactions between population growth and migration and environmental change; (2) the effects of trade and global economic activity on the value of environmental resources such as fertile farmlands, wetlands, coastal zones, and forests; (3) the relationship between institutional behavior and decision making and global environmental changes; and (4) how the rate of development and diffusion of technology affects the rate of environmental change.

- ***Understanding the consequences of global environmental change.*** Most of the anticipated consequences of climate change, including effects on human health, agriculture, and natural resources, have not been quantified. Because of the large uncertainties involved, much improved estimates of the costs of potential consequences and the scale of global water- and land-use changes are needed to provide a basis for informed decisions to implement potentially costly and comprehensive response options.

  New research is needed for developing methods for valuing both market and nonmarket impacts and benefits associated with the consequences of global environmental changes, including health care costs, estimates of the value of loss of global productivity, costs to and opportunities for regional economies, and damages to vulnerable ecosystems.

- ***Developing adaptation and mitigation options.*** Options for mitigating climate change include reducing emissions of greenhouse gases and increasing the storage potential for carbon in the biosphere. Technology prediction and assessment methods are needed for evaluating new technologies for improving energy efficiency, developing renewable energy resources, and reducing fossil fuel usage. The feasibility for reforestation, afforestation, stock enhancement of marine species, and the development of climate-change resistant species needs to be studied further.

  As forecasts of seasonal to interannual climate events (floods, droughts, etc.) improve, new research will be needed to assist communities in becoming prepared for such events. Research to improve land management practices will benefit efforts to mitigate both climate change and the adverse effects of rapid changes in land use. Further research is also needed to understand the health and environmental effects of variations in UV radiation in order to evaluate response options to increased UV radiation caused by ozone depletion.

- ***Conducting integrated assessments***. Because policy decisions on complex issues such as those related to the global environment often have substantial social, economic, and political implications, the development of science policy tools to assist in decision making is needed. An example of this type of tool is one that links reduced and simplified versions of complex physical, chemical, and biological models that predict the consequences of global changes on the environment to models that assess the social and economic consequences of these changes under various policy option scenarios. Although selection of policy options still remains with the decision maker, the tools to better evaluate the consequences of implementing various options are vital to informed decisionmaking.

Selected Milestones, 1995–1998

- Contribute to the international effort to develop a long-term comprehensive global earth observation system by launching the first in a series of earth observing system satellites, and establish a global change data and information system to make high-quality global change data accessible to researchers worldwide.

- Incorporate new understanding of atmospheric radiation processes (including the role of clouds and aerosols), ecosystem processes, and social and economic driving forces into improved coupled ocean-atmosphere-land surface models to predict future long-term changes in climate.

- Observe and document changes in the earth's stratospheric ozone layer through both space- and surface-based observation systems, and observe and document corresponding changes in UV radiation at the earth's surface through development of an intercalibrated network for monitoring UV radiation. Observe changes in human and ecosystem health related to changes in surface UV radiation and evaluate processes leading to health and environmental changes from increases in UV radiation. Evaluate the effects on the ozone layer and the health and environmental risks of alternatives to CFCs and other halons.

- Provide regular forecasts of the timing and distribution of extreme climatic events (flooding, droughts, etc.) related to seasonal to interannual climate variability (from such phenomena as the El Nino-southern Oscillation) to communities to assist them in developing plans for preventing damage from climate-related disasters.

- Develop regional assessments of vulnerability to climate change and evaluate the potential social, economic, and human health effects on communities and the effects on local natural ecosystems, agricultural, forest, fishery, and water supply resources, which would occur if climate changes consistent within the range predicted by the IPCC were to occur.

- Fulfill the U.S. commitment to establish strong international cooperation on global change research by supporting credible, internationally developed research programs (e.g., the International Geosphere-Biosphere Program, World Climate Research Program, and Human Dimensions of Global Environmental Change Program), the development of regional research institutes (such as the Inter-American Institute and the SysTem for Analysis, Research, and Training) and international assessments (such as that of the IPCC).

Research Successes

Preparing for the Future through Science & Technology March 1995

Scientists Unravel the Mystery of the Ozone "Hole"

International agreements to protect the ozone layer were made possible by a combination of comprehensive research and observation studies, establishment of an international scientific consensus, effective science-policy links, and breakthroughs by industry to develop substitutes for ozone-destroying compounds. These agreements are to decrease and eventually eliminate releases of ozone depletors into the atmosphere.

The stratospheric ozone layer is the earth's shield against solar ultraviolet radiation. More ultraviolet radiation would reach the earth's surface with a loss of the ozone "filter," potentially increasing incidences of skin cancer and cataracts, diminishing human immune systems, and damaging biota. Measurements of the chemicals that maintain the ozone layer played a fundamental role in developing control policies by providing the evidence necessary to support the theory that releases of chlorofluorocarbons (CFCs) could cause ozone depletions on the order of several percent sometime in the middle of the 21st century. Researchers also discovered that actual depletions during the 1980s were even greater than predicted, especially in the Antarctic where the remarkable ozone "hole"—with losses as large as 60%—was observed.

Atmospheric measurements confirm that emissions of the major ozone-damaging compounds will be largely eliminated. Scientists and policymakers now continue to struggle with evaluating the success or failure of the recovery of the ozone layer in the 21st century and understanding the emerging science-policy links between ozone depletion and surface climate change.

Forecasting Reduces Agricultural Losses

Early forecasts of the dramatic shifts every few years in the timing and intensity of precipitation patterns associated with El Nino have enabled farmers in several South American countries to prevent crop losses of hundreds of millions of dollars, keeping food available and prices from rising sharply. This improved forecasting capability was developed over the past ten years with research into the causes of El Nino by the United States and other countries through the International Tropical Ocean-Global Atmosphere Program.

Adverse and fluctuating weather events on a large scale cause billions of dollars in crop losses and other economic impacts each year. Drought in the Sahara, delayed monsoons in India, and prolonged dry periods in food-growing and water resource regions create food and water shortages for large populations. Even in developed countries such as the United States, events such as the Great Plains droughts of 1988, the Mississippi River floods of 1993, and the California floods of 1995 cost millions of dollars in damages and crop losses.

El Nino affects weather from Australia to South and Central America, as well as into the western and southern United States. Although fluctuations in the weather cannot be prevented, the ability to predict extreme changes months in advance allows for agricultural yields to be protected by changing crops and planting schedules. Our improved forecasting ability is sufficiently accurate to also be applied to water resource planning in the southwestern United States. Water supplies can be protected by adjusting storage and management practices.

Natural Disaster Reduction

The goal of federal research in natural disaster reduction is to provide the scientific information necessary to make our society resilient to natural disasters by reducing the loss of life, property damage, and economic disruption caused by earthquakes, floods, hurricanes, tornados, fires, and volcanoes. This goal can only be achieved through integrated efforts in the areas of assessment, mitigation, and warning. Federal research in natural disaster reduction focuses on the development of the predictive understanding, technological capabilities, and societal frameworks necessary for a sustainable society that is resilient to natural hazards.

Current State of Understanding

Although the understanding of the physical characteristics of many natural hazards has increased dramatically over the past decade, much more can be achieved to allow for timely prediction of many hazards. Important progress has been made in predicting the effects of earthquakes and in delineating zones of potential damage, but many potentially active fault zones remain unidentified. Furthermore, prediction of earthquakes themselves remains elusive. Volcano monitoring has reached an advanced stage, and the importance of certain precursors for many eruptions is now recognized. The use of Doppler radar systems, together with high-speed computers that allow forecasters to diagnose and comprehend the state of the atmosphere in a more detailed way, has dramatically advanced our understanding of severe weather. However, we still cannot predict, or interpret, many events. For example, there is currently no fully accepted explanation of the entire causal series of processes responsible for the 1993 Midwest floods.

Relevant Policies, Issues, and Legislation

- **Reducing the impact of natural hazards on safety and environmental quality as directed by the Comprehensive Environmental Response, Compensation, and Liability Act, the nuclear Waste Policy Act of 1982, *et seq.*, and the Clean Air Act Amendments of 1990**
- **Robert T. Stafford Disaster Relief and Emergency Assistance Act, as amended**
- **Earthquake Hazards Reduction Act, as amended, and the Weather Service Modernization Act, Supporting the National Oceanic and Atmospheric Administration 1993 Reauthorization Act**
- **The National Flood Insurance Act of 1968, as amended, and The Flood Disaster Protection Act of 1973, as amended**

Although the physical forces responsible for natural disasters are at least partially understood, a clear understanding of the socioeconomic forces needed to reduce natural disasters, versus those that exacerbate the problem, is only now coming into focus. A knowledge of the role of massive urbanization, technological advance, globalization of society, and cultural diversity in changing societal vulnerability to natural hazards is particularly rudimentary, as is our understanding of the options and opportunities for reducing the impact of natural hazards and adapting to their occurrence. Especially worrisome is the prospect of more complex, massive disasters in the world of the future.

The major policy tool of the past has been insurance, and as the scale and costs of natural disasters have grown, casualty insurers are threatened with massive future losses. What is needed is the application of new technologies that will allow structures and lifelines to withstand hazards so that societal, and personal, losses are decreased. Information on technological solutions and other forms of natural disaster reduction have been made available to the pubic sector, but much of the information remains fragmented and difficult to access.

Research Program

Important ongoing research and development in natural disaster reductions focuses on improved understanding of the nature and impact of hazards and the means to mitigate risks. Important ongoing research activities receiving strong emphasis include:

- *Observations and analysis to determine the fundamental controls on natural hazards* and the links between climate, weather, and physical and biological hazards, such as earthquakes, volcanic eruptions, and pestilence.

- *Characterization of how structures and lifelines respond to natural hazards* and how new engineering and earth science technologies can be used to mitigate the effects of natural disasters.

- *Developing faster, more reliable warning systems* through integration of observational and analysis research with new information systems.

- *Assessing the socioeconomic forces needed to reduce natural disaster impacts* by improved understanding of individual and group response and vulnerability to natural disasters and opportunities for safer behavior.

- *Developing integrated natural hazards risk assessments* that include scientific, technological, and socioeconomic information.

Areas of Enhanced Emphasis

The agencies conducting research in natural disaster reduction recognize the need for coordinated federal research and close collaboration among federal agencies, state and local governments, the private sector, and the general public in three important areas:

- ***Research addressing specific hazards***. Building societal resilience to specific hazards is an effective approach toward natural disaster reduction. Such programs are especially effective when they begin with risk assessment, including a mitigation emphasis, pay special attention to socioeconomic impacts and aspects of the problem, and address warning and dissemination needs. Several programs of this type are either under way or in the planning and preparation stages; they include the National Earthquake Hazards Reduction Program, the U.S. Weather Research Program, and the National Space Weather Program.

- ***A comprehensive national risk assessment.*** The United States must improve characterization and assessment of natural hazards risk. The physical and biological risk of specific natural hazards, the interactions between natural hazards and natural and human-made environments, the functional viability of communities, and the cost-benefit implications of various policy options must be quantified. These analyses will be integrated to develop a national risk assessment that will contain the following elements: a summary of recent disasters, a comparison of past losses with the predictions of previous risk assessments, assessment of risk in future years, identification of special risks by type and/or by geographical area, and highlights of advances in methodology and national capabilities.

- ***Development of an information network to support the National Mitigation Strategy.*** The National Mitigation Strategy has defined its goals as: "By the year 2020, to engender a fundamental change in public attitude which demands safer communities in which to live and work, and thereby to reduce by at least half, the loss of life, injuries, economic costs . . . and destruction of natural and cultural resources which result from the occurrence of natural disasters." To speed the transfer of research and technology advances into operational practice so that this goal can be accomplished, the federal agencies will develop an information network built on the National Information Infrastructure.

Selected Milestones, 1995—1998

- ▶ Make publicly available through Internet an information system to support the National Mitigation Strategy. This will increase the tools available to local communities for natural disaster reduction.

- ▶ Identify weather-sensitive industries, and work collaboratively with them to assess the economic impacts of severe weather; implement a framework under the U.S. Weather Research Program for increasing the benefit of severe weather forecasts to these industries.

- ▶ Complete a plan for national risk assessment, which will guide U.S. planning for natural disaster avoidance and response.

- ▶ Develop and distribute improved hazard warnings, and increase the effectiveness of hazard warnings in ensuring human safety through mechanisms for stakeholder feedback (including policymakers, community planners, emergency response personnel, the general populace, and special populations).

- ▶ Develop new technologies and engineering techniques for the seismic safety of new and existing buildings and lifelines, and implement new guidelines to enhance public safety and building resilience.

- ▶ Develop an interagency system to provide real-time, accurate, and reliable observations of geomagnetic storms and solar wind, which can seriously compromise satellite operations and electric power delivery, and develop the capability to make 10-year geomagnetic storm forecasts.

Research Successes

Preparing for the Future through Science & Technology — March 1995

Philippines Escape Volcanic Disaster

Tens of thousands of lives and hundreds of millions of dollars worth of military property were saved by timely evacuation before the volcanic eruption of Mount Pinatubo in the Philippines. The eruption in June 1991 was the century's second largest volcanic eruption. Lives and property were saved by the quick response of Philippino scientists and civil defense authorities, assisted by the U.S. Geological Survey (USGS) and the Volcanic Crisis Assistance Team from the USAID Office of Foreign Disaster Assistance. USGS scientists provided vital upgrades in radio-telemetered, computer-assisted monitoring and critical experience that they have gained through work on volcanic crises around the world. Through long-term obsevation and study of active volcanoes, together with detailed investigations of the geology and geochemistry of older, inactive volcanoes, USGS scientists have discovered several means of predicting volcanic eruptions.

More than 65,000 people (including 14,500 American military personnel and dependents from nearby Clark Air Base) were evacuated before the climactic eruption. The death toll was about 150, including one American citizen.

Since the massive eruptions at Mount Pinatubo, volcanic mudflows (lahars) have threatened about half a million people and have left more than 60,000 homeless. U.S.-designed technology is the basis for immediate warnings of lahars, and the U.S. has continued to assist the Philippine Institute of Volcanology and Seismology in providing warnings to the national and local governments. USGS experience from the United States and other countries also has been the principal basis for long-range forecasts of lahars and downstream sediment problems. This information is critical for political decisions about social and engineering measures to cope with the lahars and for engineering design of lahar-controlling structures.

Timely Hurricane Warnings Save Lives, Property

Improved accuracy and lead time have significantly decreased the number of hurricane-related deaths, particularly since the middle of this century. Such early warning is now possible because of significant improvements in the science and technology of weather observation and analyses, together with vastly improved communications technology. Hurricane Andrew in 1992, for example, was tracked the moment it came off the coast of Africa. Initially it was considered only a minor tropical storm, even as late as Friday morning, August 21. As its increasing strength was recognized, however, a hurricane watch was issued for the south Florida coast. A hurricane warning was issued at 8 a.m. Sunday, and Andrew struck Dade County, Florida, at 3:49 a.m. Monday. During the warning, radio and television stations devoted air time to tracking the storm, relaying official bulletins, discussing its potential severity, and providing guidance on preparation and evacuation.

The majority of Dade County residents reported they had sufficient warning to prepare for the storm and that television had been their principal source of information. Early warning allowed almost 750,000 people to evacuate the area. The impact of the hurricane was catastrophic, estimated at $30 billion in property damage. Remarkably, however, only 15 deaths were directly attributed to Andrew, despite the huge number of evacuees.

Resource Use and Management

The goal of federal R&D on resource use and management is to promote the management, conservation, and use of natural resources in ways that sustain and enhance terrestrial and marine ecosystems and the quality of life. This broad goal has three subcomponents: (1) link research to resource management at various temporal and spatial scales; (2) develop the science base and the technologies for determining the mix of resources that will promote sustainability; and (3) determine how best to sustain and use a given resource across landscapes and the seascape.

Many of the goods and services that are essential for society's well-being are provided by forests and rangelands; fisheries; and ore coal, oil, and gas resources. Specific policy questions include: What are the amounts, distribution, and status of various renewable and nonrenewable resources? What are the noncommodity, off-site, or unintended impacts and tradeoffs of resource use and management options? What new or improved management systems or technologies can be developed to further sustainable resource use? What are appropriate roles for local, regional, and national resource management policies, and how can they be integrated?

Relevant Policies, Issues, and Legislation

- Clean Water Act
- National Environmental Policy Act
- National Forest Management Act
- Renewable Natural Resources Act
- Renewable National Resources Research Act
- Endangered Species Act
- U.S. Climate Change Action Plan
- North American Free Trade Agreement
- National Geologic Mapping Act
- Magnuson Fisheries Conservation and Management Act

Current State of Understanding

Research has generated the scientific information base needed to assist the nation in managing its land, water, and mineral resources and in formulating wise environmental policies. Although there is a tremendous array of inventories to assess physical and biological resources, most were initiated to provide resource- specific information. Currently, there is little coordination among these efforts in terms of spatial or temporal scales, and few attempts have been made to harness these data bases to each other. In many cases, it is not new information that is needed but rather the integration of existing data bases.

Research directed at helping resource managers modify management strategies to respond to new scientific information or complex societal demands is insufficient. Research to devise management practices for renewable resources has generally led to the development of systems that maximize one or a few objectives rather than optimizing for many end points simultaneously. For both renewable and nonrenewable resource extraction, the existing methodologies tend to address site-specific impacts reasonably well, with less understanding being developed of off-site impacts, cumulative effects over time, and the consequences of management actions at a specific location on social, economic, and environmental issues at the landscape level.

Research Program

Research on which comprehensive resource use and management decisions depend includes geological and mineral and energy resource assessments and studies of the ecological, economic, and social factors involved in the development and management of offshore oil, gas, and mineral resources. Programs also include the development of new mineral methods of recovery that safeguard workers and prevent environmental harm. Other programs support the efficient and environmentally benign use and management of domestic energy resources; renewable marine and coastal resource and ecosystem health assessments and management; monitoring activities, modeling, and information management; and vessel and aircraft support operations. Research also develops new resource management and restoration practices and assesses the long-term effects of agriculture, forestry, fishing, recreation and environmental changes on the quality and productivity of natural resources.

Areas of Enhanced Emphasis

- ***Assessment of resources and their uses.*** Renewable and nonrenewable resources will be inventoried and monitored to assess their potential for sustainable use on local and global scales. This information is critical for natural resource development and management decisions.

- ***Research to understand integrated systems.*** New research will focus on the interrelated functions and dynamics of ecological, technological, economic, social, and political factors associated with natural resource systems, including use by humans and societal benefits. Development of an information base on these interrelationships is essential to evaluate tradeoffs between resources, resource mix, and alternative uses and to predict the direct and indirect effects of human activity and natural variability on the environment. This research should include monetary and nonmonetary valuation of benefits for alternative uses of natural resources.

- ***Development of options and methods for resource use and management.*** Better ways are needed to use resources in order to increase the potential level of sustainable production, increase the value of natural resource products, and reduce the costs of resource use, while developing innovative methods to use, restore, and enhance ecosystems.

- ***Application of scientific information to resource use policy and management.*** New methodologies and practices are needed to integrate science into natural resource and management policy decisions at all levels of government, nationally and internationally. Methods include the development development of predictive models, decision support systems, risk assessments, and other tools to integrate and convey natural, social, and economic sciences information to policymakers.

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Selected Milestones, 1995–1998

- Define the protocols and techniques needed for integrated resource assessments. These techniques include indicators and measures of resource abundance, condition, availability, and use for both renewable and nonrenewable natural resources. This information is essential to improve the scientific basis for informed long- and short-range resource-use policies that balance socioeconomic and ecological priorities.

- Establish an integrated data base that links socioeconomic factors to measures of natural resource conditions and trends. These data will be geo-referenced and linked to predictive models that evaluate tradeoffs between various resource-use mixes and alternatives. These models will provide the capability to evaluate and compare alternative management, use, and policy options at local, regional, and national scales that balance socioeconomic and environmental factors.

- Define and implement site-specific and regional natural resource condition indicators that reflect the local and regional impacts of management activities. These indicators will help identify pilot locations and issues where adaptive management principles can be tested. This approach will provide the ability to monitor and minimize significant negative impacts to the environment and society through adaptive management.

- Provide new or modified methods and management systems, for both renewable and nonrenewable resources, that are cost effective and that minimize environmental damage associated with consumptive and non-consumptive uses. This will increase the efficiency of resource use and minimize the cost associated with loss of environmental benefits or site remediation.

- Determine ways to extend the service life of materials, or improve recycling technologies to reduce consumptive use of renewable and nonrenewable resources. These technologies will increase the efficiency of resource use and effectively increase the supply of natural resources.

Research Successes

Preparing for the Future through Science & Technology March 1995

Forest Research Meets Society's Demand for Multiple Uses

Research has enabled us to manage both public and private forests for multiple uses, while maintaining environmental quality. Forests provide either directly or indirectly many of the goods and services that are essential for society's well being, including such diverse products as clean water, food, medicines, fiber, minerals, and recreation. The United States now has the same extent of forest cover that it did 100 years ago. Research has led to the development of guidelines for managing naturally regenerated forests for multiple-use objectives, as well as methods to intensively manage forest plantations for fiber production, while maintaining environmental quality both on- and off-site. Harvested forest products from both plantations and natural stands represent 4% of our import and export trade volume and 2.5% of our gross national product. Currently, the average annual growth of tree volume across all land ownerships exceeds harvest by more than 25%. This has been accomplished in spite of the fact that during the past 25 years our nation's population has grown by more than 22%, while our demand for wood fiber has increased by 55%. In addition, timely research programs on forest health threats, such as the southern pine beetle and catastrophic fires, have led to the development and implementation of effective operational guidelines that greatly constrain the extent of environmental and economics loss.

As environmental concerns have expanded, so too has research to increase understanding of how forested ecosystems function as a complex relationship of their component organisms. This has led to major advances in how forests are managed. For example, logging systems have been developed that minimize soil compaction and erosion, thereby sustaining long-term soil productivity and avoiding damage to streams and aquatic life. While some endangered species legally require the development of scientifically credible protection plans, we have learned how to modify management practices to maintain viable populations of many species of plants and animals before their survival becomes compromised and how to restore some populations that were at one time threatened.

Fisheries and Stream Quality

Federal water quality research has identified as significant threats to fisheries and water quality both point-source pollution and pesticides and fertilizers from diffuse sources, such as agriculture and households. The cumulative effects of various land uses have, at times, degraded freshwater streams. In some instances this has led to the decline or elimination of fish populations, recreation values, and drinking water quality.

Research on modified agricultural tillage practices and how to best maintain or restore riparian buffer zones has reduced soil erosion and stream contamination. This has enabled us to maintain fish spawning areas. Research also has provided an understanding of the important role of small side streams, water temperature, and woody debris in providing critical fish rearing habitats. The result has been increased fish populations and improved water quality in several regions of the country.

Toxic Substances and Hazardous and Solid Waste

The goal of federal toxic substances and hazardous and solid waste research is to prevent or reduce human and ecological exposure to toxic materials, such as pesticide residues, polychlorinated biphenyls (PCBs), and lead, and their adverse consequences by providing the scientific and technical information needed for informed decision and policy-making and effective problem solving.

Toxic substances and solid and hazardous wastes have potential adverse impacts to human health and ecological systems. The nation spends over $100 billion per year on environmental controls, much of which are to address toxic substances and wastes. Control strategies are based on our best understanding of the potential risks and the most effective ways of reducing them. Gaps in our scientific knowledge result in incomplete or inefficient risk identification and management. Filling these gaps reduces the uncertainties in risk assessments and ensures availability of more cost- effective risk management approaches, both of which can improve our levels of protection and the cost effectiveness of management approaches, potentially saving billions of dollars in management costs.

Relevant Policies, Issues, and Legislation

- Toxic Substances Control Act
- Federal Insecticide, Fungicide, and Rodenticide Act
- Resource Conservation and Recovery Act
- Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
- Occupational Safety and Health Act
- Clean Air Act
- Clean Water Act
- Safe Drinking Water Act
- Atomic Energy Act

Research on toxic materials focuses on improving the characterization and communication of risks; developing cost-effective policies for managing exposures to toxic materials; and developing cost-effective, innovative solutions for pollution avoidance, control, and remediation.

Current State of Understanding

Research in the area of toxic substances and wastes can be segmented into two categories: risk assessment and risk management (pollution prevention, controls, remediation, and monitoring).

Until recently, most risk assessment efforts for toxic substances focused primarily on potential causes of cancer. The risks of other human health effects (e.g., neurological, developmental, and reproductive) and ecological impacts have received far less attention. Generally speaking, the information available for human health or ecological risk assessments for the more than 70,000 chemicals in commerce is either incomplete or inadequate to estimate risks precisely. Comprehensive data bases on cancer and noncancer end points are available on very few toxic substances. In addition, the data often are inadequate to extrapolate from animals to humans and from high levels of exposure where animal observations are made to much lower levels more characteristic of ambient concentrations of contamination. Differing individual genetic susceptibilities to the toxic effects from environmental chemicals may produce a wide range of responses. The absence of critical data in these areas may lead to large uncertainties in risk estimates. Uncertainties also arise from the unknowns associated with the biological and environmental fate of toxic chemicals.

Past research on risk management has focused heavily on control and remediation technologies and on characterization and monitoring. Emphasis has been placed on field evaluation for remediation technologies. Although many effective technologies have been developed or evaluated, more cost-effective approaches are needed, especially for certain toxics or types of contamination. More recently, research has begun to emphasize pollution prevention. Significant efforts have focused on developing and disseminating crosscutting tools and methods for evaluating pollution prevention alternatives. Some generic process research, as well as joint research with certain industry sectors, has also been done, but much greater emphasis is needed in these latter areas.

Research Program

Important ongoing research is being conducted on risk assessment, including research to assess and reduce the impacts associated with exposure to toxic materials, methods and predictive models, fate and transport processes to assess exposure, and data integration to characterize risks. In the area of risk management, research activities are focusing on developing and demonstrating technologies for reducing and preventing the generation of toxic materials, controlling their release into the environment, and remediating hazardous waste sites. The intent is to cost-share risk management activities through dollar leveraging to stretch federal R&D funding for improved cost and program effectiveness.

Areas of Enhanced Emphasis

- ***Improving risk assessment capabilities.*** Increased research will focus on making risk assessment a more effective tool for decision makers by developing and improving models for estimating and predicting exposure and environmental fate; better understanding the biological and ecological mechanisms of action for toxic materials; improving methods for monitoring and assessing exposure, and understanding the variability of susceptibility within populations, including the effects on vulnerable populations. This knowledge is fundamental to prioritizing risk, selecting risk management strategies, and setting cost-effective risk reduction goals.

- ***Improving risk management tools.*** Two components of risk management will be emphasized. First, pollution prevention will become a major thrust for research activities, focusing on development and evaluation of cleaner products, processes, and technologies in partnership with industry and other stakeholders. Second, recognizing that the nation has a huge existing burden of sites contaminated with toxic materials with enormous potential cleanup costs, federal research efforts will emphasize development and demonstration of better, faster, safer, and more cost-effective technologies to remediate hazardous and mixed waste sites, including improved technologies for characterizing and monitoring contaminants at sites. Federal research will also emphasize programs to facilitate faster commercialization of innovative technologies, including government and private sector partnerships.

Selected Milestones, 1995—1998

- Produce a national research strategy on endocrine-disrupter chemicals. Such chemicals (e.g., DDT and some PCBs) may cause hormone-related problems such as decreased fertility in humans and certain types of hormone-related cancers (e.g., breast cancer) and may be associated with ecological problems such as wildlife population loss. This research strategy will lead to a better understanding of whether or not these chemicals cause significant public health or ecological effects and the need for policies to mitigate such impacts.

- Finalize the reassessment of the health and ecological effects from exposure to dioxin and related compounds. This reassessment has major implications because of the ubiquitous exposure and the potential of these compounds to cause harm at low levels of exposure. This assessment will have major impacts on regulations to control emissions on dioxins, as well as future pollution prevention efforts.

- Conduct cooperative research with industry partners to develop technological improvements to reduce inefficiency, substitute cleaner and less toxic chemicals, reduce costs, and improve environmental performance.

- Provide improved exposure models for hazardous air pollutants (HAPs). Health effects and exposure research will help characterize the potential risks from HAPs emitted from a wide variety of sources from chemical plants to drycleaners. This exposure research is needed to support risk analyses for regulated sources of HAPs, which the Clean Air Act requires to be completed by 1997 to 1998.

- Improve ecological risk characterization by better defining the responses of communities and ecosystems to toxic chemical stresses.

- Implement a national program to verify performance of innovative environmental technologies. Performance verification is needed to enable commercialization of technologies that can improve environmental performance and reduce costs. Select a pilot program in 1995, begin operation in 1996, and expand the program in 1997.

Research Successes

Preparing for the Future through Science & Technology — March 1995

75% Reduction in Blood Lead Levels in Children

During the past two decades, health assessments have demonstrated adverse effects resulting from lower exposures to lead than previously recognized. At high doses lead can cause psychiatric and neurological changes, digestive problems, kidney failure, and death. We now know that in children much lower doses of lead adversely affects nervous system development, learning ability, and behavior.

In the late 1970s, 88% of American children between the ages of one to five had blood lead concentrations above levels that health experts now consider safe. In the United States, exposures to lead have resulted from flaking and chalking lead-based paint, drinking water contaminated by lead pipes and fixtures, and air pollution from leaded gasoline and other sources.

Research on exposures and the effects of lead formed the basis for government actions such as the ban on the use of lead house paint, lead-soldered cans, and the phasing down of lead additives in gasoline. As a result, the amount of lead in the average American's bloodstream fell more than 75% over the past 15 years, and only 8.9% of American children now have blood lead levels that are considered hazardous.

The challenge today is to address residual lead risks for people, particularly children, who live in low-income housing with lead paint hazards. The U.S. Environmental Protection Agency, Department of Health and Human Services, National Institute of Environmental Health Sciences, Department of Housing and Urban Development, and Centers for Disease Control have a coordinated strategy to address these risks.

New Technologies Clean Up Hazardous Waste Faster, Cheaper

New remediation technologies can significantly lower costs and shorten the time for cleaning up contaminated soils and groundwater. Previously, treatment involved simply pumping and treating groundwater and excavating soils. A new technology, in situ air stripping, injects air through a horizontal well. The diffused air contains the hazardous chemicals and is transported to the surface via another well in which gases are extracted. This process is now accepted as the industry standard and is five times more cost effective than the traditional pump-and-treat technology.

Cooperative research between federal research laboratories and private industry has successfully developed other new technologies. The Petroleum Environmental Research Forum, for example, has demonstrated that certain nutrients will greatly increase the breakdown of toxic chemicals by microbes indigenous to some soils. This research shows that the microbes nourished in a specific area form a biological barrier, or "microbial filter," and convert contaminants into clean water and carbon dioxide. This technology can be used to clean up oil spills from underground storage tanks. The breakdown of such compounds in situ, opposed to having to be removed from the site, provides a far more cost-effective cleanup method.

Water Resources and Coastal and Marine Environments

The goal of research on water resources and coastal and marine environments is to provide the scientific basis for managing water resources and aquatic environments to ensure adequate, quality water resources for domestic, industrial, agricultural, fishery, transportation, recreation, and other uses to meet equitably and efficiently the needs of present and future generations and to ensure the integrity, productivity, diversity, and vitality of lake, stream, estuary, and ocean coastal ecosystems. Research focuses on characterizing the status and predicting trends in the quality, distribution, and use of the nation's water resources and aquatic ecosystems.

Relevant Policies, Issues, and Legislation

- **Clean Water Act provisions for assessments of water and watershed status and trends and criteria/standards development for management and enforcement**
- **Coastal Zone Management Act wetlands protection and nonpoint sources of pollution provisions**
- **Marine Protection, Research, and Sanctuaries Act; Oil Pollution Act; National Coastal Monitoring Act; and other environmental statute provisions for water and aquatic ecosystem quality assessment**

Current State of Understanding

Many groundwater and surface water systems are hydraulically connected, and land-use and water-use practices within those watersheds affect water quality. However, management decisions and monitoring programs frequently are based only on surface water or groundwater quantity and quality considerations and, therefore, are too narrowly focused. Management of and policies regarding the availability, quality, and flow of water resources are dependent on integrated models of these resource systems, especially the dynamics of their physical, chemical, and biological interactions. Existing models lack the complexity required to realistically simulate actual conditions and are of limited use in projecting system response to future conditions. For important issues such as competition for limited water resources, which results in conflicts between irrigation, industrial, and municipal water use and requirements for hydroelectric peaking power, recreation, and endangered species habitat protection, new modeling capability is evolving that will couple climatic, meteorological, hydrological, and river-basin management models to aid management and policy decisions. However, at present many decisions on watershed management, land use, and water quality regulation are still being based on overly simplistic understanding of complex natural conditions.

The cumulative effects of waste disposal, toxic chemical contamination, and watershed alteration have resulted in severe but generally local degradation of the nation's water quality and accompanying aquatic environments. Currently, no integrated understanding exists of the nonpoint sources of contamination and the combined effects of these contaminants on water resources and ecosystems. An ability to understand and predict cumulative effects on water resources and ecosystems is needed for efficient and effective solutions.

Some progress has been made in understanding the effects on coastal and inland aquatic ecosystems of nutrient and sediment loading, toxic chemicals, and water diversions. Less progress has been made in understanding the structure and function of sensitive habitats and the cumulative effects of disturbance. This type of information is needed to improve management decisions that must balance resource use with a sustainable system and for the definition of criteria for determining whether restoration is appropriate or successful. Developing a predictive understanding of the interactions among natural forces, environmental quality, ecosystem use, and their relationship to social and economic dynamics is essential to moving systems management from a reactive mode to a proactive one that benefits both societal and natural systems.

Research Program

Vital ongoing research includes nationwide assessments using remote sensing techniques and in situ observations to collect data. Advanced mapping methods of the sources and processes that affect the movement of water, sediment, and chemical constituents are being developed. Other research activities focus on understanding the structure, function, and dynamics of land margins and other aquatic ecosystems, including how specific habitats function to support living marine resources and how these linkages are affected by human and natural stresses. Models of aquatic ecosystems, indicators of ecosystem health, and methods and protocols for restoring water resources and aquatic ecosystems are being developed. In addition, predictive systems management techniques are being developed for integrating multiple geographic data bases and applications into geographic information systems. These will be used to develop appropriate strategies for regional ecosystem management.

Areas of Increased Emphasis

- ***Integrating monitoring efforts*.** Coordinated monitoring will stress the need to provide accurate information, combining remotely sensed and in situ observations, on the status and trends of the quantity and quality of all U.S. surface, ground, and coastal waters and watersheds. Emphasis will be on developing a national monitoring program to link and expand the various ongoing aquatic environmental quality and other data collection programs into one coordinated national framework as recommended by the Intergovernmental Task Force on Monitoring Water Quality.

- ***Predicting water availability and flow*.** Improved modeling and prediction of water resources and aquatic ecosystem status and trends will depend on a better understanding of the structure and function of water flow patterns, particularly how they are affected by human activities. Focus will be on developing improved observation systems and predictive models of water resource distributions and dynamics that will lead to a new class of predictions and forecasts of both site-specific and regional application.

- ***Understanding the interactions among water quality and aquatic ecosystem functions*.** Research will focus on improving our understanding of the links between water quality and aquatic ecosystem health and our assessments and predictions of responses of water quality and aquatic habitats to cumulative stressors resulting from human activities.

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- ***Improving ecological restoration and rehabilitation capabilities.*** Improving our ability to protect, restore, or rehabilitate damaged and lost aquatic habitats is a critical element for sustainable use of many watersheds. Research will be directed toward better understanding how natural and restored systems operate, developing cost-effective restoration capabilities, and identifying realistic measures against which restored systems can be evaluated.

- ***Enabling capabilities for predictive systems management.*** Predictive management of ecosystems requires an improved understanding of both natural and human-induced processes so that decision makers can implement the appropriate mix of strategies to sustain and enhance the quality of aquatic resources for current and future needs. Research will focus on the development of new science and management paradigms that encourage interactive and multidisciplinary approaches to evaluate best management practices, apply new types of ecological engineering and planning, implement ecosystem management efforts in specific geographic regions, and integrate natural and social sciences into the decision-making process.

Selected Milestones, 1995–1998

- Complete mapping and change detection of coastal land cover for all major coastal areas of the United States, including the coordinated management and dissemination of the change-detection data sets and management applications derived from them.

- Complete data collection, interpretation, and report preparation for the first 20 National Water-Quality Assessment Program sites, and initiate detailed planning for the final 20 sites.

- Provide new, regional algorithms for remotely monitoring water mass movement, algal pigments, and productivity in coastal and estuarine water from satellites and aircraft.

- Complete a peer-reviewed, comprehensive national assessment of the U.S. coastal environment that integrates evaluations of the state of the natural environment with assessments of the effectiveness of current governance mechanisms and structures and the social and economic effects of environmental change.

- Provide improved assessment and field tools for predicting the cumulative effects of multiple stressors and carrying capacities in U.S. coastal and estuarine systems.

Research Successes

Preparing for the Future through Science & Technology — March 1995

What's in Your Water Besides H_2O and Why?

Comprehensive water resource studies, dependent on the long-term national infrastructure provided by U.S. Government Scientists, provide the credible assessments necessary for reasoned debates over water resource development, regulation, and protection. Equally comprehensive and credible research cannot be accomplished alone by other entities such as states or universities.

For example, anecdotal information in the mid-1980s indicated that groundwaters in the midwest might be widely contaminated by certain herbicides from nonpoint sources, suggesting the need to undertake extensive monitoring and ban many useful agricultural chemicals. The United States took groundwater samples from shallow wells under corn and soybean fields across 12 midwestern states and found none that exceeded health advisory levels for those herbicides in drinking water. These results have not only calmed unwarranted fears but also saved substantial monitoring costs for the state agencies responsible for protecting public water supplies.

The U.S. Geological Survey investigation demonstrated that in many midwestern states herbicide contamination of groundwater is a seasonal problem and that expensive water treatment and monitoring can be reduced greatly for eight months of the year. It also showed that herbicide concentrations in reservoirs remain relatively high throughout the year. States such as Kansas have used this information to target their efforts to control herbicide use in specific high-risk watersheds.

Satellite "Eyes" Land Use Change

Data bases, unimaginable only a decade ago, are allowing researchers and resource managers to study regional land cover and to detect change over large areas. A new Federal Coastal Change Analysis Program is combining satellite imagery, aerial photography, and field data into large data bases that enable scientists to monitor and analyze a wide range of environmental issues. These geographic information systems are valuable tools to effectively monitor coastal habitat changes and to understand some of their biological consequences.

Scientific monitoring, research, and analysis have recently helped lead to an unprecedented consensus of all stakeholders concerning the need to restore the south Florida ecosystem. The restoration efforts address the complexity of the system and will require reconfiguration of canals to return the flow of water essential to the functioning of the Everglades ecosystem. Remote sensing tools, such as these land cover and change detection techniques, are being used to facilitate the reconfiguration effort. They also will be used to evaluate the success of management actions by linking the actions to responses downstream and in the ocean. These efforts are drawing federal, state, and local stakeholders together in a united effort to achieve scientifically sound management practices for south Florida's unique ecosystem.

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Chapter 4

Crosscutting Needs for Integrated Environmental Research and Development

An effective, efficient, integrated research program must support informed policies for managing the environment and natural resources. Achieving this support requires a long-term commitment to a balanced research program of monitoring; data and information management; studies of fundamental chemical, physical, or biological processes; assessments and characterizations of potential environmental threats; and the development of new technologies for preventing or managing hazards.

The Committee on Environment and Natural Resources (CENR) relies on the findings and recommendations of the seven issue subcommittees to prioritize policy-relevant research to fill critical gaps in our understanding of the natural environment, the impacts of human activities on the environment, and the influences of environmental change on human (both biological and social) and ecological systems. In contrast, the three crosscutting subcommittees and two working groups span all the environmental areas addressed by the seven issue subcommittees. The crosscutting needs for environmental research were developed as an outcome of the CENR National Forum; they are:

Crosscutting needs of environmental R&D

- Ecological systems research
- Observations and data management
- Research on socioeconomic dimensions of environmental change
- Environmental technology
- Science policy tools: integrated assessments and characterization of risks

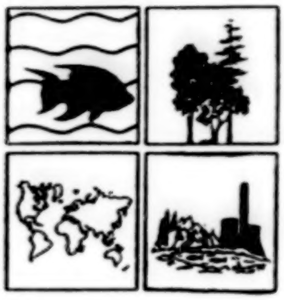
- *Ecological systems research* to understand the natural and human forces driving interactions among biodiversity, ecosystem dynamics, and management. A solid scientific base is essential to better anticipate change and sustainably manage the ecosystems we depend on (e.g., forests and agriculture).

- *Observations and data management* to formulate and test predictive models that help us anticipate environmental problems. Effective management is increasingly important as the quantity of data grows and its forms diversify. Priorities are being set regarding what data should be collected. Interagency cooperation in both data collection and management is critical to avoid costly overlap.

- *Research on socioeconomic dimensions of environmental change* to concentrate on the interaction between societal drivers, such as economic growth and international trade, and environmental change. Policies must be evaluated in terms of their effectiveness in preventing, managing, and ameliorating environmental problems.
- *Environmental technology* to remediate existing environmental contamination and move toward avoidance of environmental harm in all sectors of our economy.

- *Science policy tools* to strengthen links between scientific assessments and formation of environmental policy. Of particular importance to enhance open dialogues about environmental issues are integrated assessments and effective characterization of environmental risks and uncertainties in scientific knowledge.

Ecosystem Research



National and international policymakers and managers are moving more toward including ecosystem perspectives in their decisions, and federal agencies are committed to advancing the scientific basis for these actions. Ecosystem research requires a multidisciplinary approach that examines the physical and biotic interactions between human activities and land, water, and air at various geographic scales. This approach involves developing a better understanding of the structure, function, and dynamics of ecological processes to predict ecosystem vulnerability to change, and the consequences of societal action or inaction at scales ranging from local to global, and for time frames from days to centuries.

Monitoring, research, modeling, and assessment tools are needed to address these issues. To promote coordination between federal programs with similar ecosystem-related objectives, the CENR has formed a working group to integrate ecosystem R&D needs across all relevant issue areas. (The Ecosystem Research Working Group is composed of members from all the CENR subcommittees.) Representatives from the White House Ecosystem Management Initiative provide an important link to policy and decision makers.

Ecosystem research needs

- Documenting change in ecosystems.
- Understanding processes and the effect of scale.
- Synthesizing and assessing ecological data and information.
- Predicting ecological change.
- Interactions of human and ecological systems.
- Restoration and management of ecological systems.

Environmental Goal

The goal is to develop a coordinated approach for providing the fundamental understanding of ecological systems necessary for assessing the ecological consequences of environmental change. This goal will promote the efficient use of natural resources to achieve desired social benefits (uses, products, or values) while sustaining ecosystem integrity (health, biological diversity, and function) for future generations by developing science-based principles for ecosystem management, and a predictive understanding of ecological impacts of environmental change.

Key Policy Objectives

An important challenge is to provide a mechanism for reconciling conflicting management objectives within a single ecological unit. An ecosystem approach requires that resource managers deal explicitly with the broader goals of multiple resources, constituents, jurisdictions, and ownerships. Through this new effort, resource managers will have a better scientific basis for integrating ecological, biophysical, and socioeconomic information into decisions. Other key issues relate to understanding ecosystems in order to detect and evaluate consequences associated with changing stresses.

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Exotic Species Threatening Economy is Example of Need for Ecosystem Research

The zebra mussel, accidentally introduced into North America, causes severe fouling of municipal and private drinking water systems, electric power generators, and industrial water intakes. Once inside an intake conduit, zebra mussels attach to surfaces, grow, and form colonies many inches thick. These colonies restrict water flow, obstruct valves, and clog heat exchangers and condensers. The mussels also impact aquatic food webs, ecosystems, commercial and sport fishing, boating and navigation, agricultural irrigation, aquaculture, and the recreational use of beaches. It has been estimated that the economic impact of this organism in the United States could total billion of dollars annually by the end of the 1990s.

The zebra mussel is a small, bivalved mollusk native to Europe and western Asia that was imported to the United States in ballast water from ships traveling internationally. Since its discovery in the Great Lakes in 1988, the zebra mussel has spread into North American fresh water resources, particularly throughout the Great Lakes and Mississippi River Basin and their navigable tributaries. Its introduction is one example of hundreds of nonindigenous species that have the potential to detrimentally affect ecological and economic systems. Biodiversity and ecosystem dynamics research provides the necessary baseline understanding of ecosystem processes to anticipate the impact of exotic species on indigenous species and ecosystems. Timely research on the biology, life history, and physiology of nonindigenous species, their effects on the environment and human activities, and their potential for becoming an economic factor are required to identify effective techniques for prevention, detection, monitoring, and control.

Areas of Enhanced Emphasis

A common set of ecological science elements have emerged from the discussions of this working group, in conjunction with the planning activities of their respective issue subcommittees. These common elements define the areas of enhanced emphasis for CENR ecosystem research.

There is a need to provide a strong scientific basis for managing ecological systems in a sustainable manner. This need reflects concern both for the unintended consequences of human activities on ecological systems, such as effects of pollutants, climate change, and increases in carbon dioxide, and for the continued utility of ecological systems as providers of goods and services to society.

It is imperative that we understand and quantify the drivers of change in ecological systems. These drivers include both natural processes, such as weather and interannual climatic variability, and anthropogenic stresses such as extractive and non-extractive resource uses, impacts of pollutants, and physical alterations of the landscape. Understanding the importance of the influence and magnitude of different drivers of change, the collective influence of multiple stresses, the ecological consequences of the changes, and the feedbacks between ecosystems and their physical environments (e.g., composition of the atmosphere or ocean, land use, water quality, sediment flux) are all critical to developing strategies for sustainable development. The identification and understanding of these drivers is an inherent part of the following areas of enhanced emphasis for ecosystem research:

- ***Documenting change in ecological systems.*** The CENR recognizes the importance of maintaining long-term monitoring and measurement activities guided by both scientific and managerial concerns, in order to enable the quantitative determination of whether effects of changing management, natural stresses and their dynamics, or unintended anthropogenic stresses are large or small.

- ***Understanding processes in ecological systems.*** There is a need to better understand the processes that govern the character of ecosystems, control their natural dynamics, and regulate the ways in which they respond to natural or anthropogenic stresses. Understanding the relationship of ecosystem structure to function is key to understanding the role of biological diversity in ecosystem sustainability. Process level information is critical to assessment, and to prediction of response to future change.

- ***Synthesizing and assessing ecological data and information.*** Determining the vulnerability of ecosystems to environmental change, or documenting the consequences of environmental change on ecological systems creates a critical demand for synthesis of available knowledge and modeling capabilities through an assessment process. Assessments play important roles in considering the significance of such issues as the effects of biodiversity loss on ecosystem integrity, or of climate change on ecosystem function.

- ***Predicting ecological change.*** Research targeted at developing enhanced capability to predict ecosystem response to change is of high priority. Uncertainty associated with prediction is reduced through increased understanding of critical processes related to system function, while verification of predictions requires effective utilization of existing monitoring and measurement programs along with strategically targeted new data collection efforts.

- ***Interactions of human and ecological systems.*** Societal demands for such ecosystem attributes as clean water, food, fiber, and recreation depend on biological processes and ecological systems. The many demands placed on these systems require an improved understanding of the social and economic value of the ecosystems. Efforts are being expanded to understand how social and economic forces interact with ecosystem attributes such as biodiversity, or food and fiber production. This information will facilitate the sustainable use of essential ecosystem components and functions.

- ***Restoration, rehabilitation, and management of ecological systems.*** A serious issue of high priority is the restoration and rehabilitation of ecosystems that have already been damaged. The methods by which this may be done are underdeveloped. Enhanced efforts will include research directed toward better understanding of how natural and restored ecosystems operate; development of cost-effective restoration capabilities; and identification of realistic standards against which ecosystem restoration can be evaluated.

Selected Milestones, 1995–1998

- Define common objectives and principles for the organization and the conduct of ecosystem monitoring, research, prediction, analysis, and assessment. These objectives and principles could include, for example, criteria for selecting sites for ecosystem monitoring networks as geographically targeted laboratories to improve science-based ecosystem management and/or as U.S. contributions to international programs.

- Identify key products that should result from ecosystem R&D such as the documentation and prediction of status and trends in ecosystems, assessments of vulnerabilities, assessments of driving forces and consequences of change, adaptive management strategies, and criteria for coordination, and ensure the compatibility of ecosystem research with long-term objectives related to resource use, land management, or global and international agreements.

- Test models that include comprehensive treatment of ecological processes and influences in predictive climate models, and use these models to develop preliminary regional scenarios of climate change and to assess the environmental consequences of climate change on ecosystems and societal support systems such as agriculture, water resources, transport, and commerce.

Research Successes

Preparing for the Future through Science & Technology March 1995

Chesapeake Bay Ecosystem Restored

A restoration campaign for the Chesapeake Bay has begun to show signs of great success, especially with the full recovery of its striped bass population. The Chesapeake Bay is a vast natural resource with significant economic, recreational, and social value to the region and to the nation. Of the estuaries in the United Sates, the Chesapeake is the biggest and most bountiful, a coastal sea capable of sustaining as much life for its size as anywhere on earth. The bay is home to more than 2,700 species of plants and animals and is visited by millions of people each year, providing huge economic benefits to the region.

The Chesapeake has suffered from the effects of more than two centuries of steady growth, increasing pollution and runoff, and accumulation of sediment and industrial wastes. However, the ailing bay ecosystem has begun to rebound, largely because of the efforts of the Chesapeake Bay Program over the past decade. This is a unique public-private endeavor composed of governments in Pennsylvania, Maryland, Virginia, and the District of Columbia working with the federal government and local citizens and businesses.

The major environmental problems of the Chesapeake Bay and its tributaries were investigated by a comprehensive study initiated by the U.S. Government in 1975 at the request of Congress. As a result of this research, management strategies to control nutrients, toxins, wetlands alteration, shoreline erosion, hydrologic modification, and dredging were implemented. Strategies for managing shoreline development and the effects of boating and shipping on water quality were also developed.

In 1985, Maryland and Virginia imposed a moratorium on striped bass fishing in response to extremely low catches, overharvesting, and survey data about spawning. The states lifted their moratorium in 1990 after a successful spawn of the species in the upper and lower bay, but tight regulation of the fishery continues. Biologists, however, have now logged record numbers of newly spawned fish in the bay and project continued population increases in the years ahead. Declaring recovery of the striped bass has cleared the way for relaxation of catch restrictions in the Chesapeake.

Interdisciplinary research ranging from understanding the behavior and transport of nutrient and toxic chemicals in the watershed, to fish population dynamics and predictive modeling contributed to the management strategies taken. Scientists and resource managers hope to apply lessons from the striped bass conservation effort to other important fish stocks that are declining all along the east coast.

Observations and Data Management

Extensive earth observation and monitoring are a critical component of environmental and natural resource research that is aimed at advancing scientific understanding and developing predictive assessment capabilities, products, and services. Such observations, collected by ground-based, airborne, and satellite systems, result in enormous quantities of global, regional, and local data that must be adequately managed to be of use. Because researchers must be able to access, combine, and interrelate many different types of data from various sources, and because of the relatively high cost of the observation and data management systems, the CENR has adopted a strategic approach to these two fundamental activities that cut across all areas of environmental R&D. The coordination of observation and data management efforts also ensures that the data necessary to answer the questions of highest priority to both scientists and policymakers are being gathered and distributed and that U.S. efforts are taking full advantage of, and being sufficiently coordinated with, international efforts.

Environmental Goals

The CENR is working to inventory and integrate the nation's observation and data system requirements and capabilities. This work includes assessing the overlaps and gaps in existing capabilities and prioritizing new initiatives. This effort will lead to the development of a more comprehensive system of global and national observation and monitoring systems and a complementary data management system to ensure that environmental and natural resource information is widely and easily available to all stakeholders, consistent with our policy of full, open access to data.

Key Policy Objectives

The CENR serves as the U.S. focal point for international global observing system programs such as the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS), and the Global Ocean Observing System (GOOS). These programs are sponsored by intergovernmental and nongovernmental organizations including the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization, the United Nations Environment Program (UNEP), and the International Council of Scientific Unions (ICSU). These programs link existing and planned national systems and serve as the basis for a comprehensive global observing system.

Areas of Enhanced Emphasis

Links are in place to make environmental and natural resource data of broader value to society. These include:

- ***linking local-scale data collection efforts with regional- and global-scale efforts*** to enable the respective causes, effects, and interactions to be determined;

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- ***linking remote sensing data from satellites with in situ measurements*** ("ground truth data");
- ***linking socioeconomic data with data on the natural environment***, the importance of which is demonstrated by the growing use of geographic information systems that allow businesses and researchers to overlay Landsat data, weather data, and population and income data; and
- ***making the agency environmental data and information available*** in forms useful to the public, educators, policymakers at all levels, business activities, and researchers.

Although the United States and many other nations are collecting critical environmental and natural resource data, successfully understanding many aspects of environmental science will require the implementation of an international policy of open and stable exchange of data and information. The United States promotes the continuance and extension of the full and open exchange of all environmental data and related information at no more than the marginal cost of fulfilling specific user requests.

Selected Milestones, 1995—1998

Near-term objectives in the area of observations and data management include the following:

- ▶ Identify priority observation and information requirements for environmental research and the development of a strategy to close information gaps, identify redundancies, and ensure efficient allocations of resources.
- ▶ Complete an electronic index of key environmental and natural resource data sets, allowing easy access by all users through the information superhighway to data available in various U.S. data and information systems such as including the Global Change Data and Information System, the Federal Geographic Data System, and the National Environmental Data Index.
- ▶ Develop implementation strategies for the U.S. components of an international global observing system, including the associated data and information system, to ensure that U.S. activities are being appropriately coordinated with other relevant international efforts in order to leverage U.S. resources. The effort associated with making global-scale observations is greater than any one nation can undertake; therefore, international cooperation allows for the application of resources to common problems while minimizing unnecessary duplication of effort.
- ▶ Implement the Global Change Data and Information System based on its recently approved interagency plan to make data widely and readily available while ensuring the quality, compatibility, accessibility, and archiving of valuable global change information.
- ▶ Complete mapping and change detection of coastal land cover for all major coastal areas of the United States.
- ▶ Computerize and make accessible the data records for existing species specimen collections.
- ▶ Develop an integrated information base on the ecological, technological, socioeconomic, and political factors associated with natural resource systems, and link these data to predictive models that evaluate tradeoffs between resources, resource mixes, and alternative uses.

Earth Observing System (EOS)

To advance scientific understanding of the entire earth system, it is essential that global observations are collected and made available to a broad range of users. The best way to accomplish this is through a program of long-term observations from space. To achieve this goal, U.S. agencies are cooperating with other countries in developing an international Earth Observing System (EOS). EOS is a series of polar-orbiting and lower-inclination satellites that will provide global observations of the land surface, oceans, ice sheets, and atmosphere over a minimum of 15 years. This timeframe of continuous observation is critical to the study of climate change processes, which are annual to decadal in length, and to enable researchers to distinguish natural variation from human-induced changes.

EOS will greatly enhance our ability to understand and predict the effects of many parts of the complex earth system, including:

- *Water and energy cycles*. Cloud formation, dissipation, and radiative properties influence the response of the atmosphere to greenhouse forcing and are key to understanding precipitation and evaporation that moderate the earth's temperature.
- *Oceans*. Understanding the exchange of energy, water, and chemicals between the ocean and atmosphere and between upper and lower layers of the ocean is critical to the eventual prediction of El Nino events and other phenomena of great consequence to agriculture and fishing.
- *Chemistry of troposphere and lower stratosphere*. The troposphere is where we live, and changes in the concentration of trace gases can affect ecosystems in the process of influencing climate change.
- *Land-surface hydrology and ecosystem processes*. Land cover change, sources and sinks of greenhouse gases, exchange of moisture and energy between land and atmosphere, and water runoff from land surface to oceans are all interwoven and play an important role in regional and global water resources required by agriculture and industry.
- *Glaciers and polar ice sheets*. Changes in size and movement must be tracked as a key measure of global climate change. These changes are important determinants of sea-level change and of the global fresh water balance.
- *Chemistry of the stratosphere*. This is the arena of ozone loss, which has demonstrated the need for studying chemical reactions, solar-atmosphere effects, and sources and sinks of greenhouse gases to assess adverse impacts of reduced ozone and increased ultraviolet radiation on the earth's ecosystems.
- *Solid earth*. Volcanoes have a major influence on atmospheric chemistry and temperature, and their role must be understood to complete the climate change picture.

EOS data on these components of the earth system will be analyzed by more than 700 scientists and 200 graduate students funded by the EOS program and by the broader national and international scientific community. In addition to 19 instrument science teams, 29 interdisciplinary science investigations are under way to increase the use and utility of existing satellite data and to prepare for use of the new types of data expected from new EOS instruments.

EOS data will be made available to these and other researches worldwide by the Earth Observing System Data and Information System (EOSDIS). The principal component of a larger Global Change Data and Information System, EOSDIS provides "one-stop shopping" for users of data and data products from EOS and related satellites through a set of discipline-oriented Distributed Active Archive Centers. EOSDIS is evolutionary in its development, growing in capability as new computer technologies and new observational capabilities become available. Currently, a version 0 of EOSDIS is making data available from operating and past satellites that are important precursors to EOS, such as the Upper Atmosphere Research Satellite, TOPEX/Poseidon, Landsat 4/5, the Earth Radiation Budget Experiment, and the operational meteorological satellites.

EOS supports interdisciplinary science investigations, training of the next generation of earth system scientists, new observational capabilities during an extended period of 15 years, and a comprehensive data and information system. These capabilities will enable scientists to move from qualitative to quantitative, and from descriptive to predictive, study of the earth system. The knowledge gained will be used to assess the impact of natural and human-induced changes in the global climate system and to make the difficult policy decisions that lie ahead.

Research Successes

Preparing for the Future through Science & Technology March 1995

$4M Saved in Data Processing

Interagency coordination and federal and university collaboration have led to the development of an interagency memorandum of understanding to formalize the Multi-Resolution Land Characteristics (MRLC) Consortium. This effort establishes the basis for the joint acquisition and processing of Landsat Thematic Mapper imagery for the coterminous U.S. and sets the stage for implementation of joint research activities and the development of a flexible and functional land characteristics data base. This joint effort has already saved the government $4 million in satellite imagery costs and is expected to result in a savings of some $26 million in indirect costs related to satellite data processing and data archiving.

Satellites Link Land Use, Productivity

Since the early 1970s, increasingly sophisticated satellites, beginning with Landsat, have provided an invaluable record of land-use changes. Around the globe, major forested areas are being cut to provide land for agricultural use (even in regions where soil fertility is low and water resources are meager) reducing water quality and fish habitat, losing buffer zones for floods, inducing erosion and loss of soil productivity, and reducing the diversity of plants and animals that form the base for agriculture and biotechnology. In addition to such direct effects are indirect effects that include altering global biogeochemical cycles, the local climate, and wildlife habitats. Such changes also allow the invasion of new, and often destructive, species.

Over the past decade researchers have documented destruction of tropical rain forests and the burning of grasslands, the shifting edge of the world's deserts, expansion of urban areas, and areas of flooding and drought. These observations allow researchers to inventory global ecosystems and natural resources and their changes over time, information vital to sustaining agricultural and water resource systems.

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Social and Economic Dimensions of Environmental Change

The social and economic sciences represent a critical component of any research agenda on environmental change. The environment is home to the human activities that people have shaped to establish their communities and improve their quality of life. Neither that environment nor human activities remain static. Just as the geologic record provides a lens on changes over millennia in earth systems, so does the archaeological record contain a wealth of information on human communities under varying environmental conditions. Comparative studies of contemporary societies show that the use humans make of land impacts on the quality and availability of natural resources. What the studies reveal, too, is that the size, composition, and location of human populations both mold and are molded by environmental conditions. Finally, the research illustrates that environmental effects are not randomly distributed across societies or population groups. Essentially, research in the social and economic sciences aims to clarify how human activities affect the environment; how environmental changes affect our society and its component groups; and how we and our institutions respond to environmental change.

The extant research—on land use, population change, economic incentives, cultural values, individual preferences—has advanced our understanding of the interplay between human and environmental forces. It shows, for example, that people's perceptions of risk affect quite significantly their responses to hazards. There are patterns to these perceptions. Among other things, people generally regard events they control as less risky than those over which they have little influence. Needed now are analyses that translate findings from across the social, economic, and other sciences into temporal and territorial scales that are meaningful for human and community activity.

Research Needs for Social and Economic Dimensions of Environmental Change

- Examine societal factors influencing environmental changes, such as population growth, economic development, and international trade.
- Analyze policy instruments and decision tools, including the design, comparison, and *ex poste* evaluation of policies undertaken to address environmental problems.
- Identify social, economic, and institutional barriers to the diffusion of environmental technologies and evaluate the measure of policies to reduce them.
- Develop methods to measure nonmarket values of environmental amenities and to calculate national resource accounts.

Industrial societies have developed an array of instruments to prevent or mitigate the impacts of environmental dislocations. These societies seek the same end through the development of technologies that are benign to the environment, or that remediate environmental problems. What remains to be deciphered are the conditions that permit the effective development and deployment of innovative technologies and instruments of public policy.

Environmental Goals

The CENR strives to mobilize the resources of the social and economic sciences to answer central questions about the relationship between human behavior, well-being, and the environment. Federally sponsored research in the social, behavioral, and economic sciences provides a foundation on which knowledge about the interaction of human, physical, and biological systems can be built. This research aids in the design and evaluation of environmental policies, enhances understanding of the role of human activity for critical environmental issues, and helps to identify issues and policies that can affect the highest social and economic returns.

Key Policy Objectives

Efforts to improve environmental management and regulation have evolved over the past two decades, a period of profound social and economic change in the United States and elsewhere. Stronger economic bonds around the globe, and acknowledgement that environmental problems transcend borders, have changed the landscape for research and policy. Industrial and industrializing nations increasingly recognize the importance of common solutions that can ease environmental threats without exacerbating regional and local disparities.

Policies about the environment do not occur in isolation from other policy questions. Communities across the United States struggle to determine levels of acceptable risks for pesticides; the regulations appropriate for protecting fisheries and marine life; and mechanisms for preserving jobs and protecting endangered species. The social and economic sciences cannot resolve such policy dilemmas. These sciences can contribute, however, by identifying innovative policy options and management strategies, and specifying their trade-offs, options, and their probable consequences.

Areas of Enhanced Emphasis

Long-term research is needed on human-environmental interactions and system dynamics. Their complexity requires greater collaboration of physical, life, and engineering scientists with social scientists than usually prevails. Greater expertise is needed, too, on the diversity of values that drive environmental concerns, that affect preferences and trade-offs, and that govern resource use and management.

- ***Fundamental human and social processes.*** Informed policy demands an understanding of human beings as component and prime custodian of the environment. High priority should be given to improving our knowledge of the fundamental human and social processes that affect our use of the earth.

- ***Policy instruments and decision tools.*** Decisionmakers need a better portfolio of policy instruments for encompassing a broad set of environmental, social and economic goals and for balancing the effectiveness and distributional outcomes of alternative solutions. The development of improved methodologies is essential for allocating scarce resources as efficiently as possible.

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- ***Barriers to information flow and technology diffusion.*** This research focuses on improving the flow of information between the research and policy communities and between and within the public and private sectors; it includes a better understanding of the factors responsible for the diffusion of technologies in the industrial, commercial, and household sectors. This research will identify existing institutional barriers to market penetration and will identify, develop, and pilot strategies and incentives to shorten the commercialization pathway.

Selected Milestones, 1995–1998

- Improve computational and modeling methods for linking data, drawn from different times and locales, on human-environmental interactions.
- Establish the social and economic processes through which environmentally benigh technologies are designed and adopted, in developed and developing countries.
- Improve methods for examining risk in complex and interdependent physical, engineering, and social environments in order to design more effective risk management systems.
- Develop sound methodologies for policy analysis that can provide non-market valuation of resources, environmental attributes, and ecosystems.
- Improve communication links between fundamental researchers in the social and economic sciences and analysts of policies on the environment and natural resources.
- Develop innovative policy and management approaches that enhance efficiency and equity in environmental and natural resource management.

Research Successes

Preparing for the Future through Science & Technology **March 1995**

Identifying Social and Economic Impacts of Resource Management Decisions

Marine fisheries are a primary domestic natural resource under stress. When fishery resources become limited, fishermen lose their jobs and families suffer. Domestic fishery management approaches need to be evaluated and redesigned. Social science research is helping identify social and economic impacts of the current trends to move from open access fisheries to limited access fishery management with quasi property rights associated with the right to fish. Social scientists have identified the distributional effects of cutbacks in harvesting and limited access management, and have projected effects on industry consolidation and processing sectors. Federal and academic economists have identified the rationalizing effects that limited access is projected to have on fisheries, as well as the impacts differentiated by ethnic group, community, vessel size, and other factors. The data and findings are being used by Fishery Management Councils and by federal offices in order to form programmatic decisions about social and fishery programs for hard-hit regions.

Advancing the Science of Valuation

More sensitive methodologies for valuing natural resources are being developed by federal agencies in cooperation with university scientists. A leading candidate in environmental economics methodologies is the development of more refined contingent valuation methods, particularly for use in damage assessments of natural resources (litigation applications). A panel of nationally-known economists was convened to inform the development of regulations for performing NRDA under the Oil Pollution Act of 1990. The Panel concluded that CV can produce estimates reliable enough to be presented in a judicial or administrative determination of natural resource damages, including passive use value, provided that such studies adhere closely to guidelines described in their report. The Panel also identified issues for further research, in part to explore whether alternative procedures, such as generic (rather than incident-specific) studies, could provide reliable estimates at a lower cost.

Humans Adapt to Changes in Climate

Improved forecasts of climate patterns aid agricultural production. But recent research shows a more intricate relationship between climate change and farming than had been assumed. The evidence comes from a study on climate, farm prices, and type of crop for nearly 3,000 counties in the United States. The study discovered that higher than normal temperatures—in all seasons except the fall—reduced crop prices. Greater than normal precipitation in winter, spring, and fall increased those prices. These patterns resulted from the active response that farmers made to the environmental variations. The repertoire of responses included the introduction of new crops or new technologies, and conversion of the land to other activities. The study reinforces a theme found in other research on human activity and the environment: environmental forces do not invariably produce identical social and economic outcomes, given the interventions that human beings can make.

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Environmental Technology

As the world's population and economies grow, there will be increasing stress placed on both natural and human systems. Technology will play a critical role in mitigating these pressures and in allowing our society to provide key goods and services with reduced environmental impacts. The primary goal of this research strategy is to develop environmental technologies that increase our productivity, reduce environmental problems, and create wealth and jobs. This goal cannot be accomplished by the federal government alone but will require a broad range of partnerships and integrated policies to ensure that our investments in R&D result in environmentally efficient products and services for both the U.S. and global markets. We are committed to building those partnerships both within the government and with industry, universities, nongovernmental organizations, and state and local governments.

Besides providing the knowledge base for developing environmentally sound technologies, research is also needed to help us achieve a better understanding of various technological options, their costs, and benefits. Our long-term research therefore addresses predictive modeling and assessment to determine where environmental technologies might best be deployed and how they might perform.

International coordination of R&D programs through the efforts of the Committee on International Science, Engineering, and Technology will help ensure cross-fertilization and cooperation with R&D in other countries. Consideration of global technology needs, such as special needs of developing countries for sustainable technologies, will help broaden the applicability of technology research results.

Research Needs for Environmental Technology

- **Facilitate a fundamental shift from cleanup to the avoidance of environmental harm.**
- **Develop systemic technological solutions that cut across media, processes, organizations, sectors, and geographic areas and that solve multiple problems simultaneously.**
- **Integrate R&D activities within the government, and with the private sector, that are necessary to develop these new solutions.**
- **Ensure that federally funded research on environmental technologies achieves commercial benefit, resulting in marketable products, processes, and approaches.**

Finally, a significant cost to the nation's economy is incurred by cleaning up wastes already in the environment from past actions and inefficiencies in earlier systems of production. Estimates for the cleanup of abandoned hazardous waste sites and inactive federal facilities, for example, range from $100 billion to $1 trillion over the next 20 years. Research to find cost-effective site characterization and remediation technologies is an important element in this strategy.

Over the coming decades, R&D will be the key to establishing new technological solutions and environmental management options. As the Vice President recently remarked, ". . . we must shift to fundamentally new technology trajectories rather than just increase our pace along the same old technological paths." The enabling knowledge for the next generation of environmental technologies and practices is being built now in our laboratories, universities, and classrooms. This strategy seeks to capitalize on our innovative capacity and provide the technological solutions to existing and future environmental challenges.

Environmental Goals

The Administration supports the development of innovative technologies for improving environmental quality, sustaining our natural resource base, and contributing to long-term economic growth and job creation. To maintain its strength over the coming decades, the U.S. economy must be able to deliver high-quality products and services to domestic and world markets with significantly less energy and material inputs and a dramatic decrease in environmental impacts. Environmental technologies and practices are needed to increase the overall productivity of our energy, food, manufacturing, transportation, building, and service sectors by significantly reducing energy, materials, and other inputs. Environmental technologies also are needed to heal harm from past process inefficiencies.

Key Policy Objectives

Avoiding successive generations of technology-induced environmental problems is one of the greatest challenges facing our research enterprise. The transformation of environmentally sound ideas into innovations (and eventually marketable commodities and practices) typically takes 5 to 15 years. In the case of large physical infrastructures that deliver our energy, food, water, and transportation services, the substitution of new technologies often requires 40 to 50 years. Clearly, the economic costs of traveling down any number of suboptimal, unsustainable technology paths is high.

The National Science and Technology Council (NSTC) report *Technology for a Sustainable Future* sketches a long-term scenario (30 to 40 years) that emphasizes a move away from cleanup and control to a future built on anticipation, avoidance, and assessment. The report emphasizes the need to develop more cost-effective means to remediate existing environmental problems in the short term, while shifting to a new avoidance trajectory. The diffusion of new technologies into the marketplace should be accelerated through partnerships with industry, state and local governments, academia, and nongovernmental organizations. Our challenge is to speed the evolution from pollution control and waste management to avoidance of environmental harm and resource conservation and restoration, while continuing to aggressively clean up existing environmental hazards.

Environmental technology research addresses a wide range of environmental problems by increasing environmental and resource-use efficiency of production processes, developing new approaches for remediating and restoring damaged systems, and improving our ability to monitor and assess the environmental impacts of technological innovation and interventions (both real and proposed).

Areas of Enhanced Emphasis

Research priorities reflect the need to deal cost effectively with today's environmental harm while exploring and shifting to new system paradigms that avoid environmental harm.

- ***Industrial ecology and lean production.*** The research priority is to develop a more comprehensive understanding of the flows and uses of materials and energy in our industrial system and the implications with respect to the environment and sustainable economic activity. Many industrial processes and practices will require revision or reengineering to avoid pollution and encourage recycling, and the development of more sustainable technologies and practices is needed.

- ***Clean energy, alternative energy.*** Research priorities will increasingly address economically viable sustainable or renewable energy forms that shift from control and remediation technologies for high-emission fuels to integrated production of clean renewable energy and increased efficiency of energy use in all major sectors: residential, commercial, industrial, agricultural, and transportation.

- ***Materials.*** The research priority is to develop a system of material use that is compatible with the constraints of the environment and available natural resources by reducing production of wastes, minimizing extraction and use of virgin resources, mitigating pollution, and improving energy efficiency. Also of key importance are advances in molecular modeling, computational chemistry, and molecular design to simulate on a computer the chemical and physical properties of new substances.

- ***Sustainable communities.*** The overarching technological challenge for urban areas is the redesign of the built environment in the context of the natural systems in which it exists to achieve sustainable development. Implementing this restructuring will require new technologies that will enable us to analyze and predictively model vast quantities of complex data and information links about technical, social, economic, and cultural systems. Specifically, our mid- to long-range research priority is to increase understanding of the links among the five major elements of the urban ecosystem: (1) the built environment, (2) flora and fauna, (3) wastes and water, (4) energy, and (5) transportation.

- ***Environmental biotechnology.*** A key research priority is to learn how to integrate biological and engineered systems and to continue development of biotechnological approaches to increase their effectiveness in remediation, monitoring, and control.

- ***Cost-effective remediation.*** Research priorities will focus on improving our capability to assess subsurface contamination with greater speed, higher degrees of accuracy, and lower cost and on improving the effectiveness and permanence of subsurface remediation efforts. In addition, special attention should be paid to increasing the range and effectiveness of biotechnological approaches to remediation.

Selected Milestones

- Develop a new generation of models and simulation techniques to improve our knowledge of fate and transport phenomena in the subsurface environment, and facilitate the optimization of remediation techniques.

- Expand data collection and analytic efforts to define existing and anticipated material and energy flow patterns and trends, as well as their implications for sustainable production systems. These efforts include developing and improving understanding of the impacts of material and energy flows and substitutions on the environment and the creation of regional data bases for materials.

- Develop R&D partnerships with utilities and industry to promote pollution prevention and increase the efficiency of commercial power generation and energy-intensive industries (such as refining and metal production).

- Expand R&D that is critical to reducing the cost of power generation from renewable energy resources, particularly those with high impacts on carbon emissions.

- Develop means to extend the service life of materials and improve recycling technologies to reduce consumption of renewable and nonrenewable resources (resource use).

- Characterize the process of development and adoption of environmental technologies in developing countries. Such characterization includes analysis of the influence of innovations made in industrialized countries on energy paths in developing countries in the absence of concerted efforts to facilitate technology transfer.

Research Successes

Preparing for the Future through Science & Technology March 1995

Feds Move Technology from Lab to Marketplace

A $70 million investment since the mid-1970s by the U.S. Government in cooperation with the private sector, has spawned an annual $2.5 billion market for four environmental technologies and services. As of 1993, this investment has delivered to consumers an estimated $6 billion in energy savings, and a net benefit of $10 billion is anticipated over their entire service lives. Energy savings should increase many times over as the sales of energy-efficient technologies and services continue to grow.

The technologies developed include an electronic ballast that improves the efficiency of lighting systems by up to 30% and enhances both their quality and flexibility. The current market share of electronic ballasts is 24% of all ballasts sold. The research also developed advanced energy-efficient window coatings that, although invisible to the human eye, offer a 35% increase in energy efficiency over ordinary double-glazed windows; the current market share is 36% of all windows sold. A national laboratory provides the technical and economic analysis for all residential equipment and applicable standards necessary to set mandatory efficiency levels for household appliances and heating equipment. Finally, computer software that allows building designers to evaluate the energy ramifications of complex design alternatives, was developed. Currently, this software is used in the design of about 5% of all commercial buildings (by square footage), and users report that it enables them to identify opportunities for saving another 20% of the energy used.

Automobile Industry Recycling Catalytic Converters

Platinum metals that might have been thrown away or sent overseas for recovery are now beginning to be recycled in the United States, using a patented, federally developed, recycling technology. This technology, transferred from the federal government in 1994, increases the amount of platinum, rhodium, and palladium we retrieve from discarded automobile catalytic converters. The firm expects to process some 220,000 catalytic converters per year when its facility reaches full-scale production.

Catalytic converters use platinum-based catalysts to clean engine exhaust. Although we currently salvage more than half of these devices, some are exported to Japan or Europe for processing. Foreign companies typically recover platinum by leaching the catalysts with acids or smelting them in large-scale processing operations. Such operations are not, for the most part, environmentally or financially feasible in the United States. In contrast, the new process is simple, easy to control, and environmentally sound. Estimated capital costs are considered reasonable, and none of the wastes produced require special handling. Pilot tests recovered 90% of the platinum metals from the treated catalysts. These features make the process ideal for small recycling operations.

Science Policy Tools: Integrated Assessments and Characterizations of Risks

Science policy tools for decision making provide the links between the physical, natural, social, and economic sciences and environmental policy. Technical assessments are key tools in formulating national and international environmental policies. To be useful, however, these assessments must be credible to all stakeholders, including the Administration, Congress, industry, nongovernmental organizations, and the public.

Risk assessment is a systematic process for dealing with uncertainty in decision making and for compiling information on the potential impact of chemical, biological, and physical stresses on human health, natural resources, and social systems. Risk assessment provides a framework for organizing and presenting scientific information for making policy and management decisions. Characterizations of risks may be either quantitative or qualitative, depending on the types of data available and the appropriate application of risk estimates to decision making.

Integrated Assessment is an analytical process for treating the full causal system of relationships among policies, human systems, and environmental processes. Integrated assessments ensure that interactions between human behavior and environmental change are taken into account appropriately and that the full implications of policies are evaluated. Integrated assessment of health and environmental hazards can also be used to analyze the value of various kinds of information for prioritizing policy-relevant research.

Research Needs for Science Policy Tools

- Develop methods for integrated assessments.
- Develop methods for the effective characterization and communication of assessments and uncertainty.
- Define criteria and indicators for ecosystem health.
- Enhance research on human and ecological exposure.
- Continue research on mechanisms of disease and their ecological impacts.

Human health and ecological assessments may address a range of hazards. Hazards may be characterized for exposures to one stressor from a single source, for example, or multiple stressors may be considered simultaneously. The definition of specific end points also may not be straightforward. Whereas some assessments estimate readily observed effects (e.g., death), others may be concerned with intermediate end points such as higher rates of asthma attacks or reversible, but distinct, changes in ecosystem function. Assessments play important roles in considering the significance of issues such as the effects of toxic substances on human health and ecosystems, of biodiversity loss on ecosystem integrity, and of global change on human health and ecosystem function. Of particular importance is the development of means for effective translation and conveyance of scientific knowledge gained from research and providing a forum for involving policymakers in efficiently and effectively understanding the implications of alternative policy options.

Environmental Goal

The Administration's goal is to use assessment methods to characterize, prevent, and reduce health and environmental hazards in the most effective, efficient, and fair manner. Assessments should enhance dialogues about environmental threats between scientists, managers, or policymakers and the public by effectively characterizing the potential costs of over- and under-regulation, as well as the natures and magnitudes of uncertainties and assumptions.

The Administration is committed to strengthening the methods used to perform assessments, and the CENR has developed a set of principles to guide federal agencies. These principles are broad and are intended to be applied flexibly because how particular assessments are conducted will depend on factors such as their purpose, scope, audience, and timeframe.

Key Policy Objectives

The greatest challenge facing decision makers today appears to be integrating information on different sorts of environmental threats into decisions about the most effective and efficient allocation of resources. Hazards vary not only in their source or cause (e.g., the use of hazardous chemicals, natural hazards, technological failures) but also in the types of end points they produce, in their scales (both temporally and spatially), and in their distributions across space and time. Assessments may provide a means to organize and compare information about risks associated with very different activities or sources and very different end points. Different types of data, both in their units of measurement and in their availability and reliability, may also be aggregated and/or compared.

Objectives for Developing Science Policy Tools

- Ensure consistency in assessment methods, where appropriate.
- Determine how social, cultural, and ecological concerns can be integrated into assessments.
- Define criteria for framing and determining when to undertake an assessment, considering data needs, relevance to policy, and required level of precision.
- Identify the most appropriate geographic and temporal scales for assessing different environmental problems, particularly with regard to policy needs.
- Integrate social science research into environmental assessments.
- Develop assessment methodologies for a range of endpoints and applications including natural hazards, toxic chemicals, and natural resource development.
- Assess for both humans and ecological systems variations in physiological susceptibilities of different populations and effects on especially vulnerable populations (e.g., children).
- Evaluate the impacts of, or exposures to, multiple and/or cumulative chemical, biological, and/or physical stressors to highly impacted resources or populations (e.g., workers).
- Establish methods for hazard characterization that effectively translate and communicate scientific knowledge and its attendant uncertainties.
- Develop methods for appropriately using assessments to establish management priorities.

The assessment process is integral to decision making through integration of the understanding of the relevant sciences, socioeconomics, and policy necessary for better decisions. Criteria can be developed to define when an assessment might improve policy decisions and for framing and bounding assessments so they are most appropriate and effective for policy decisions.

Principles for Environmental Assessments

- ***Be comprehensive.*** Assessments should provide decision makers with summaries of current scientific and socioeconomic understanding of changes to the environment and provide a foundation for decisions about potential policy or management strategies.
- ***Consider both natural and human-induced changes.*** Environmental change and potential ecological and economic impacts should be placed in the context of changes that are a natural part of the system's fluctuations.
- ***Begin with a broad range of inputs.*** Assessments should include a wide range of information about potential impacts, mitigation options, and adaptation strategies.
- ***Summarize concisely the state of knowledge.*** Assessments should critically evaluate the range of studies on an issue and reach as much consensus as possible. Assessments should be a common reference point for decision makers, in contrast to sporadic and separate statements reflecting the opinions of individuals.
- ***Discuss uncertainty.*** Assessments should discuss what is known and unknown and address both the majority and minority views on technical issues. Time frames for reducing uncertainty should be estimated, if possible.
- ***Undergo peer review.*** Assessments should be peer reviewed by the expert community. Several dozen to several hundred reviewers may be involved in reviewing work over the course of an assessment.
- ***Include stakeholder input.*** Stakeholders must be involved in the preparation and review of all assessments.
- ***Support international activities.*** Assessments should support U.S. participation in the preparation and review of international assessment activities related to environmental change.
- ***Develop assessment tools.*** The assessment process should further the development of policy-relevant assessment tools such as integrated assessment models and risk assessment.
- ***Establish R&D priorities.*** Assessments should clarify near- and long-term science and policy questions and help prioritize the research necessary to be responsive to policy issues.

Areas of Enhanced Emphasis

Ongoing and future research strategies must focus on strengthening the methods and models used for assessments, as well as continuing to build the foundations of scientific data upon which they are based. There is a growing recognition, for example, that exposure to environmental contaminants may cause a variety of noncancer health effects such as reproductive, developmental, immunological, and neurological effects, as well as a broad array of adverse ecological impacts.

- ***Methods for integrated assessments***. Methods will be developed further to integrate social and economic considerations into assessments of environmental threats. Such research includes establishing a stronger base of understanding about human processes and how they influence (and are influenced by) environmental change, developing generally accepted procedures for eliciting both market and nonmarket values of environmental goods and services, and evaluating the efficacy of various policy options to manage the environment and natural resources.

- ***Risk characterization and communication***. Research will be emphasized to develop and improve methods for the characterization of risks and the effective transfer of scientific information about risks and their attendant uncertainties to decision makers. Current policy controversies include calls for greater transparency of regulatory risk assessments. Critics are concerned that federal agencies do not always use the "best" scientific information and methods available, that agencies are not explicit in how they weigh other social and environmental considerations, and that risk assessment methods are not consistent across, or even within, agencies.

- ***Criteria and indicators for ecosystem health***. Important research aims to identify criteria and indicators for ecological health that are compatible with broad policy goals including protecting environmental health and ecosystem biodiversity. These criteria and indicators should be amenable to measurement and reflect structural and functional interrelationships within ecosystems. Indicators of adverse ecological effects should be integrated in framing assessments and defining relevant data needs and should assist in considering how ecological risks ought to be incorporated consistently into policy decisions. Such research should also guide monitoring efforts to identify and assess ecological disruptions that may be linked to changing environmental conditions.

- ***Human and ecological exposure***. Research on multiple and/or cumulative exposures and alternative pathways of exposure to hazardous pollutants, particularly for mixtures (both of chemicals and physical stressors), will be enhanced. This research involves the natural and physical sciences for characterizing mixtures and the biological sciences for understanding their effects. Such research should also include studies on environmental fate, that is, how contaminants disperse, react, persist, and/or accumulate. The social sciences provide a means to integrate research about human activity into assessments, understanding individual and social perceptions and responses that may influence risks or contribute to variations in exposure.

- ***Mechanisms of disease and ecological impacts***. Research will be continued to identify and predict the magnitudes of new ecological risks and human health effects. Research on biological mechanisms (both human and ecological) helps identify intermediate end points, set research and testing priorities, develop biomarkers of diseases and exposures, and understand variations in human susceptibilities to hazards. This research includes the investigations of pharmacokinetics, metabolism, and biological fate.

Selected Milestones, 1995–1998

- Complete the National Acid Precipitation Assessment Program (NAPAP) report to Congress, assessing the (1) reduction in deposition rates necessary to prevent adverse ecological effects and (2) the costs, benefits, and effectiveness of the current acid deposition control strategies mandated under Title IV of the 1990 Clean Air Act Amendments (CAAA) (air quality).

- Complete the Second Assessment of the Intergovernmental Panel on Climate Change (IPCC), a three-part IPCC assessment summarizing scientific results from around the world on the effects of human activities on climate. Initiate efforts to conduct regional and national assessments to identify vulnerabilities to climate change and the benefits and costs of various response options for dealing with or responding to climate change (global change).

- Complete a plan for a national risk assessment to guide U.S. planning for natural disaster avoidance and response through an understanding of the interactions between natural hazards and both natural and human environments (natural hazard reduction).

- Finalize the reassessment of dioxins and related compounds, evaluating health and ecological effects and exposures. This reassessment has major implications because of the ubiquity of dioxins and their association with adverse effects with very low levels of exposure (toxics).

- Produce a state-of-the-science ozone assessment, a comprehensive statement about the current knowledge of surface-ozone science, sponsored by relevant agencies, reviewed by peers and stakeholders, and timed to air decisions associated with midcourse corrections in the state implementation plans required by the CAAA (air quality).

- Complete the report for the first 20 National Water Quality Assessment Program sites, and initiate detailed planning for the final 20 sites (water resources).

- Complete a peer-reviewed, comprehensive national assessment of the U.S. coastal environment that integrates evaluations of the state of the natural environment with assessments of the effectiveness of current governance mechanisms and structures and the social and economic effects of environmental change (water resources and coastal and marine environments).

- Complete an assessment of the atmospheric effects of stratospheric aircraft (global change).

- Seek broad-based scientific consensus on select social and economic models for use in modeling of environmental decisions, such as integrated assessments of climate change.

- Develop improved methods for examining risk in complex and interdependent physical, engineering, and social environments to design more effective risk management systems.

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Assessment Unifies International Community

Research over the past 10 years, confirming changes in the composition of the atmosphere from greenhouse gases, provided the basis for the international adoption of the 1992 Framework Convention on Climate Change. Surface station measurements, air trapped in the bubbles in glacial ice, and other records all indicate that human activities since the beginning of the Industrial Revolution are changing the composition of the atmosphere faster and in ways that have not taken place for many millions of years.

In the past, changes in the composition of the atmosphere have been a major cause of climate differences. Already, observations of the global climate indicate that average temperatures are starting to warm, most likely because of increasing concentrations of greenhouse gases (especially carbon dioxide) in spite of the apparent cooling influence of the increased concentration of sulfate aerosols, primarily from sulfur dioxide emissions.

The US Global Change Research Program supported a major portion of climate change research, the results of which have been endorsed by the international scientific community and summarized in scientific assessments by the IPCC.

Appendix A

Committee on Environment and Natural Resources

Council of Chairs
Executive Committee
Points of Contact

Committee on Environment and Natural Resources
Council of Chairs

Chair	D. James Baker	NOAA
Chair	H. Ronald Pulliam	DOI
Chair	Thomas Lovejoy	SI
Chair	Robert Watson	OSTP
Vice Chair	Robert Huggett	EPA
Vice Chair	Christine Ervin	DOE
Air Quality		
Chair	Martha Krebs	DOE
Science Vice Chair	Dan Albritton	NOAA
Policy Vice Chair	Mary Nichols	EPA
Biodiversity and Ecosystem Dynamics		
Cochair	Thomas Lovejoy	SI
Cochair	H. Ronald Pulliam	DOI
Policy Vice Chair	James Lyons	USDA
Global Change Research		
Chair	Robert Corell	NSF
Science Vice Chair	Robert C. Harriss	NASA
Policy Vice Chair	Susan Tierney	DOE
Natural Disaster Reduction		
Chair	Robert M. Hamilton	DOI
Science Vice Chair	William H. Hooke	NOAA
Policy Vice Chair	Robert Volland	FEMA
Resource Use and Management		
Cochair	Jerry Sesco	USDA
Cochair	Gary Hill	DOI

Toxic Substances and Hazardous and Solid Waste

Chair	Robert Huggett	EPA
Science Vice Chair	Kenneth Olden	HHS
Policy Vice Chair	Thomas Grumbly	DOE
Policy Vice Chair	Sherri Wasserman-Goodman	DOD

Water Resources, Coastal and Marine Environments

Chair	Douglas Hall	NOAA
Science Vice Chair	Robert Hirsch	DOI
Policy Vice Chair	Robert Perciasepe	EPA

Social and Economic Sciences

Chair	Joseph Stiglitz	CEA
Science Vice Chair	Cora Marret	NSF

Joint Subcommittee on Environmental Technology

Chair	Christine Ervin	DOE

Risk Assessment

Chair	Mark Schaefer	OSTP
Science Vice Chair	George Lucier	HHS
Policy Vice Chair	Lynn Goldman	EPA

Task Force on Observation and Data Management

Chair	Charles Kennel	NASA
Vice Chair	Robert Winokur	NOAA

Ecosystem Working Group

Cochair	Donald Scavia	NOAA
Cochair	Michael Ruggiero	DOI

Office of Management and Budget

Associate Director	T. J. Glauthier	Natural Resources, Energy and Science
Deputy Associate Director	Kathy Peroff	Energy and Science
Branch Chief	Jack Fellows	Science and Space Programs

CENR Executive Committee

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Appendix B

Agency Contributions to Environmental and Natural Resource Research and Development

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U.S. Department of Agriculture (USDA)

The USDA's responsibility is to ensure a safe, healthy, abundant, and affordable food and fiber supply for the United States, while sustaining and enhancing the natural resource base. USDA research supports U.S. food, fiber, and forestry industries, which account for over 20% of the gross domestic product. Over the last decade, the department has faced challenges in the areas of water quality, biodiversity, and pest and disease control, which have required new approaches to food production and renewable natural resource management. In response to these changing needs, opportunities have surfaced in new uses for agricultural and forestry products, biofuels and biomass energy, and recycling technologies.

Contribution to the Committee on Environment and Natural Resources (CENR) Interagency Research and Development (R&D)

The USDA global change program focuses on understanding atmosphere/biosphere gas and energy exchange, altered carbon storage, the effects of increased incidence of fire, insect and disease disturbance in forest ecosystems resulting from global change, and the response of terrestrial and aquatic ecosystems to physical and chemical changes in the atmosphere. Support is provided to establish and operate a national monitoring network to obtain baseline ultraviolet-B radiation information at ground level. Research on alternatives to methyl bromide will pursue nonchemical alternatives to replace this important agricultural fumigant determined to deplete stratospheric ozone.

Research supporting biodiversity and ecosystem dynamics will increase our knowledge of how community composition, and structure relate to function and sustainability. Research in this area overlaps substantially with resource use and management. Ecosystem research addresses how a biological community and its environment interact with land use, and what practices are best for forest, range, crop and aquatic ecosystems. USDA research supports real-time policy and management decisions on threatened and endangered species, notably in the Pacific Northwest.

In the area of toxic substance/wastes, the USDA conducts research into alternatives to chemical pesticides such as crop rotations, residue, and waste management. This is part of the USDA's larger Integrated Pest Management initiative to develop environmentally benign methods to control pests and reduce pesticide risks. In addition, water resources research is designed to make better in situ use of precipitation, increase the effectiveness of water use in irrigation, minimize the adverse effects of irrigation on water quality and quantity, and improve watershed management systems and reduce nonpoint source pollution from the use of pesticides and fertilizers. Primarily in support of the extensive USDA technical assistance program, its research program in soil quality, maintenance, tillage, and erosion prediction and control provides world leadership. Air quality research emphasizes monitoring acid deposition as part of the National Acid Precipitation Assessment Program and developing technologies to reduce and control airborne particles from soil and fires. Fire safety and management research contributes to reducing natural disasters.

USDA's economic research program aids our understanding of the social and economic tradeoffs of natural resource management across all of the CENR issue areas.

The USDA has established networks with universities, government, and industry for jointly conducting research, transferring new technologies, disseminating information, and monitoring the environment with the aid of our extensive agricultural and forestry research and extension system, as well as the nonresearch efforts of the National Forest System, Natural Resource Conservation Service, Consolidated Farm Service Agency, and the National Agricultural Library.

U.S. Department of Commerce (DOC)

National Institute of Standards and Technology

The National Institute of Standards and Technology (NIST) has the primary mission to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards across a broad spectrum of activities covered by all subcommittees of the CENR. NIST supports industry through strong laboratory research, grassroots assistance to small and medium-sized companies to adopt new technologies, and rigorously competitive cost-shared awards for development of high-risk technologies with significant commercial potential. Through efforts to promote development, commercialization, and use of environmental technologies, NIST is ideally poised to help U.S. industry make the transition to green technologies and promote sustainable development..

Through its Building and Fire Research Laboratory, NIST conducts research on the life cycle quality of constructed facilities. This contributes to NIST's mission through helping U.S. industry strengthen its international competitiveness and public safety through performance prediction and measurement of technologies and technical advances that improve life cycle quality. Research areas inlcude structural, mechanical, and environmental engineering, fire science and fire safety engineering, building materials, and computer-integrated and automated construction practices.

Contributions to the CENR Interagency R&D

Air Quality, Toxic Substances. NIST maintains the National Biomonitoring Specimen Bank which stores hundreds of frozen tissue samples (e.g. human livers, fish, oysters, sea coast sediment, whale blubber) to be used for observing long-term pollution and global health trends by monitoring levels of pesticides, PCBs and over 30 trace elements. NIST also develops analytical procedures and standard reference materials for the analysis of asbestos, lead, atmospheric pollutants, soils, radon, radioactive wastes, biodegradable plastics, and other environmental contaminants. Research also focuses on the development of data, measurement and test methods, and modeling techniques to determine the performance of the building envelope and its insulation systems; the release, movement, and absorption of indoor air pollutants; the performance of building mechanical and electrical equipment; and the quality of the indoor air environment.

Environmental Technology. NIST supports research to help identify and evaluate environmentally safe replacements for ozone-depleting substances for their performance in new and existing equipment. In addition, NIST research is focused on the development of building materials ranging from environmentally benign paints, to fire resistant materials, to those with minimal vapor emissions, to those that make maximal use of recycled or waste materials.

Natural Disaster Reduction. NIST performs problem-focused research and development to improve practices, standards, and codes for new and existing buildings and lifelines to reduce loss from earthquakes, extreme winds, and fire. Research is also targeted at the development of methods to predict the behavior of fire and smoke to enable high performance of fire detection and suppression systems. NIST research also aims to identify failure mechanisms and to establish criteria to ensure structural safety.

National Oceanic and Atmospheric Administration (NOAA)

The NOAA's mission includes two equally important components: (1) promoting global environmental stewardship to conserve and wisely manage the nation's marine and coastal resources and (2) describing, monitoring, and predicting changes in the earth's environment to ensure sustainable economic opportunities.

Contribution to the CENR Interagency R&D

The NOAA is responsible for long-term monitoring of the oceans and atmosphere and provides both satellite and in situ observations, data, and information necessary to understand the earth system, assess changes to that system, and predict future changes. The NOAA's polar-orbiting and geostationary satellites provide continuous, long-term, quality environmental observations of the high seas, upper and lower atmosphere, and land areas to sustain major science programs involving global monitoring, sustainable development, climate change, coastal and marine resources, and natural disasters. NOAA data and observations will comprise a significant component of the U.S. contribution to an international global observing system, for which the CENR Task Force provides the U.S. Secretariat.

The NOAA forecasts and predicts the future state of the atmosphere, focusing its air quality research on gaining a fundamental understanding of the atmospheric processes that must be characterized for credible and useful predictions. The primary air quality issues that NOAA addresses are surface-level ozone, acidic deposition, and visibility. The NOAA addresses two important research aspects of global change--climate change and ozone depletion. The NOAA has a significant role in operational observation, research, prediction, and information management efforts for the national global change effort. The NOAA's social and economic sciences research focuses on the human dimensions of global change and the relationship of near-term climate forecasts and their impact on the economy. The NOAA provides forecasts and warnings of various natural hazards related to the atmosphere and ocean, focusing research on understanding the underlying environmental processes and predictive methodologies of natural hazards. The NOAA provides river and flood and hydrological forecasts and

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warnings for the protection of life and property. Research is geared to advanced water quantity forecasting.

The NOAA conducts an active program of monitoring and scientific research to assess the status of the nation's renewable marine resource base and their attendant uses. The NOAA pursues a multidisciplinary approach to enhance the ability of scientists and managers to identify, understand, and manage anthropogenic impacts to coastal and marine ecosystems against a background of natural system variability. NOAA's social and economic sciences research focuses on the social and economic impacts of fisheries management and damage assessment methodologies.

The NOAA supports a balanced research program on coastal and marine observations, modeling, assessment, ecosystem prediction, and information management. Ongoing research includes remote sensing, modeling of oceanic and nearshore processes, developing key indicators of coastal and marine ecosystem health, the effects of cumulative impacts on coastal and marine environments, and environmental valuation and human dimensions research.

The NOAA is responsible for research on and management of marine ecosystems and their biodiversity. Research in this area includes surveying and monitoring the abundance of and trends in marine biota, measuring and evaluating the impacts of pollution, exotic species, and habitat degradation on marine biodiversity and ecosystem integrity, and understanding and generating models to simulate large-scale marine ecosystems. The NOAA's role extends to the restoration of degraded ecosystems and establishment and management of marine and estuarine sanctuaries and reserves.

U.S. Department of Defense (DOD)

As with all other aspects of DOD's R&D, environmental and natural resource research programs are focused in the National Science and Technology Council (NSTC) Committee on National Security and contributory to the CENR.

The department invests resources in environmental and natural resources R&D to meet its responsibility to the nation to clean up its facilities; move toward forces and infrastructure that are nonpolluting; husband the lands and resources under its control; and to be compliant with federal, state, local, and international regulations. In addition, the Department's operational needs lead to investments in R&D to understand and predict the state of the operating environment (i.e., weather, oceanography, terrain) and its effects upon people, platforms, sensors, and weapon systems. Knowledge of these environmental effects leads directly to tactical and strategic military advantage, which can significantly alter the outcome of conflict. These programs are critical contributors to the CENR.

Contribution to the CENR Interagency R&D

DOD invests in R&D through Service and Defense Agency programs, the Strategic Environmental Research and Development Program, and the Environmental Security Technology Certification

Program. The investment in environmental quality is balanced among installation restoration and remediation, technologies for compliance with regulations, pollution prevention technologies, methodologies for conservation of natural and cultural resources, as well as alternate and renewable energy technologies. In characterizing and predicting the operating environment, the department invests in R&D in meteorology, oceanography, terrestrial sciences, ionospheric and space effects, global environmental change, and remote sensing of the environment.

R&D within the department is executed in response to mission-relevant requirements. Because of the wide variety of installations owned and operated by the department coupled with the necessity for us to be able to deploy our forces worldwide, the department invests in all aspects of environmental and natural resources R&D. There are DOD R&D programs that contribute to each of the CENR subcommittees with the largest investment contributing to the area of toxic substances and solid and hazardous waste research.

Department of Energy (DOE)

DOE is entrusted to contribute to the welfare of the nation by providing the technical information and the scientific and educational foundation for the technology, policy, and institutional leadership necessary to achieve efficiency in energy use, diversity in energy sources, a more productive and competitive economy, improved environmental quality, and a secure national defense.

Contribution to the CENR Interagency R&D

DOE has multiple missions, each of which uniquely contributes to the R&D portfolio for CENR. These mission areas include energy resources, environmental quality, science and technology, national security, and crosscutting programs in industrial competitiveness.

DOE conducts extensive applied R&D and maintains a dedicated national laboratory to support R&D in the area of energy efficiency and renewable energy sources. This program is targeted at achieving diversity and efficiency in energy use and efficiency in its generation of a more secure national economy. At the heart of some of the department's programs is the concept of sustainable development. Many of the these programs are linked under a conceptual framework that supports pollution avoidance, rather than the traditional end-of-the-pipe controls for industrial processes.

DOE supports substantial R&D in the area of environmental cleanup and remediation technologies. Because of the department's enormous cleanup mission, DOE is sponsoring some of the most advanced R&D nationally and internationally to determine safer, cheaper, faster, and more effective ways to clean up contaminated environments and to reduce or prevent the emission of environmental pollutants. Technology leveraging with the private sector results in cost-shared risk through dollar leveraging. The result is innovative technology systems to be transferred to the private sector for commercialization.

DOE programs in science and technology include significant contributions to global change research.

Research into the underlying phenomena, ranging from sophisticated modeling of global climate to extensive field programs to gather data on critical processes, are all part of the department's efforts in this area. Advanced sensors are being developed to further the accuracy and precision of key climatic measurements. These activities are conducted in response to DOE's need for assessing the environmental consequences of energy production and use. Additionally, the department conducts significant research into local air quality and air pollution phenomenon, providing a basic science perspective into urban air pollution issues, as well as providing analytical tools that support the prediction and mitigation of consequences from natural disasters.

The national security mission within the department is home to several contributing elements to the CENR portfolio, notably the large program for dual-use technologies that constitute the Environmentally Conscious Manufacturing Program, and separate, dedicated programs designed to conduct R&D pollution prevention technologies for use at DOE facilities and to encourage their transfer to the private sector.

Finally, the department's crosscutting programs in industrial competitiveness include specific activities to help research and develop clean, sustainable industries of the future, all based on the sustainable principles of energy efficiency, pollution prevention, and industrial ecology.

Department of Health and Human Services

National Institutes of Health

The National Institute of Environmental Health Sciences (NIEHS) has the primary responsibility at the National Institutes of Health for environmental research. Other institutes, including the National Cancer Institute (NCI), the National Eye Institute (NEI), and the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS) support environmental health studies related to cancer, eye diseases, and immune system disorders.

The Public Health Service Act directs the NIEHS to support research on the health effects of environmental agents. NIEHS research programs are broad and include research on drugs, pesticides, chemicals used in the home or workplace, electric and magnetic fields, radon, and prevention and intervention efforts. In addition, the Superfund Amendments and Reauthorization Act directs the NIEHS to support multidisciplinary research grants to determine the health and environmental effects and possible routes of exposure of toxic waste and to develop technologies for destroying or containing toxic waste. The NIEHS communications strategy encompasses training, education, technology transfer, community outreach, and most importantly, dissemination of findings from its research programs.

Contributions to the CENR Interagency R&D

Global Change. The NCI, NEI, NIAMS, and NIEHS support research on the health effects of ultraviolet (UV) and near-UV radiation on the immune system, aging process, and sensitive organs such as the eye and skin, and on methods to reduce these harmful effects. As the most prevalent human carcinogen, UV radiation is an increasingly important public health problem. Melanoma is the most rapidly increasing, potentially fatal cancer in the United States, and the costs of treatment for basal and squamous cell skin cancers, which equal or exceed in numbers all other cancers combined, result in extremely high health care costs. NIEHS also funds research on the health effects of chlorofluorocarbon (CFC) chemical replacements.

Air Quality. NIEHS supports research related to the health of indoor and outdoor air pollutants such as acid aerosols, particulates, ozone, radon, and air toxics. The focus is on identifying harmful agents, determining mechanisms by which they produce effects, and developing and evaluating the impact of prevention and intervention strategies.

Water Resources. NIEHS supports research on a wide range of contaminants of our water resources, including agricultural chemicals, heavy metals, dioxin, PCBs, solvents, and seafood-borne toxins. The institute funds five university-based Marine and Freshwater Biomedical Sciences Centers to develop fish and other marine animals to serve as biological models for toxicologic research and to study human health problems resulting from contaminated water or seafood.

Toxic Substances. NEIHS supports research, including, for example, basic study in molecular biology that led to the discovery of the breast cancer gene BRCA1 by NIEHS scientists; epidemiology studies; and toxicity and carcinogenicity testing. Research conducted by the NIEHS into the health effects from environmental agents results in the prevention of cancers from benzene, asbestos, and radiation; reproductive problems from DES, caffeine, and environmental estrogens; birth defects from lead, isoretinoin, and mercury; skin diseases from polychlorinated biphenyls (PCBs), dioxin, and naphthalenes; and neurologic problems from lead, kepone, and solvents.

NIEHS provides 95% of the funding and the day-to-day management of the National Toxicology Program, which coordinates toxicological research and testing activities within the Department of Health and Human Services and provides information about potentially toxic agents to regulatory and research agencies and the public.

Hazardous Wastes and Environmental Technologies. With funds from the Superfund Trust, the NIEHS Superfund Basic Research and Training Program supports multidisciplinary research on the health effects of hazardous substances, on strategies to detect and trace the movement of hazardous substances in the environment, and on technologies to destroy or contain hazardous substances. An important component of the health research is the search for biomarkers of exposure and effect that can identify not only those persons exposed but those most likely to suffer serious effects. Technologies under development include steam injection to remove solvents from soils (tests show one technology to be 60 times more efficient than pump-and-treat methods), bioremediation of azo-dyes and organic chemicals, and supercritical water combustion for toxics that cannot be successfully destroyed in high-temperature incinerators.

Risk Assessment. Although NIEHS does not conduct risk assessments, it provides a major portion of the science base to those agencies that do. All of its research from basic studies of the molecular and genetic basis of environmental illness to epidemiology studies of human populations to toxicologic testing of environmental agents contributes to the development of risk assessments. The understanding of the mechanisms of action of environmental agents made possible by the new tools of molecular biology coupled with state-of-the-art animal testing promise great improvement in the quality of risk assessments.

Agency for Toxic Substances and Disease Registry

The mission of the Agency for Toxic Substances and Disease Registry (ATSDR) is to prevent exposure and the adverse human health effects and diminished quality of life associated with exposure to hazardous substances from waste sites, unplanned releases, and other sources.

Contribution to CENR Interagency R&D

ATSDR evaluates data and information on the release of hazardous substances into the environment to assess any current or future impact on public health and to identify studies or actions needed to prevent human health effects. ATSDR conducts health assessments of all waste sites on the National Priorities List and in response to petitions from concerned individuals and organizations. The agency supports epidemiologic, surveillance, and other studies on toxic substances and their effects and maintains a national registry of persons exposed to hazardous substances in the environment.

Centers for Disease Control and Prevention (CDC)

The vision of the CDC is healthy people in a healthy world. Within CDC, the National Center for Environmental Health (NCEH) works to prevent and control disease, injury, and disability related to the interactions between people and their environment outside the workplace. NCEH responds rapidly to emergencies and disasters, whether the emergency is a natural disaster, a family poisoned by pesticides, or an outbreak of chemically related deaths among children in a foreign country. NCEH responds with epidemiologic, technical, and laboratory assistance.

Contribution to the CENR Interagency R&D

NCEH has ongoing programs to evaluate and prevent adverse effects on human health caused by environmental factors. These programs include studies on the effects of heat stress and air pollution on human health, childhood lead poisoning prevention, birth defects, radiation-dose reconstruction, and the effects of natural disasters on people and strategies for preventing or mitigating them. The NCEH laboratory develops methods for high-quality measurements used in exposure assessments and supports programs to ensure high-quality measurements in laboratories throughout the nation and the world.

National Institute For Occupational Safety and Health (NIOSH)

NIOSH, also at CDC, is the federal agency responsible for conducting research to prevent work-related diseases and injuries. NIOSH performs the following public health functions: (1) laboratory and field research to identify, evaluate, and prevent work-related diseases and injuries; (2) recommendations and technical assistance to agencies, employers, and workers; and (3) the training of occupational safety and health professionals.

Contribution to CENR Interagency R&D

NIOSH conducts laboratory research to evaluate potential hazards, develop technology and information needed for field studies, and develop and evaluate protective measures. Toxicologic research focuses on pulmonary, cardiovascular, carcinogenic, genotoxic, and reproductive effects, as well as research to examine mixed chemical exposures or chemical and physical agent combinations. NIOSH also conducts research on improving and assessing methods and equipment for monitoring worker exposures to chemical hazards.

U.S. Department of the Interior (DOI)

As the nation's principal conservation agency, the DOI has responsibility for most of the nation's nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The major focus of DOI R&D efforts is to provide the scientific basis for natural and cultural resource policy and management decisions.

Contribution to the CENR Interagency R&D

DOI conducts biodiversity and ecosystems R&D to provide information on the abundance, distribution, and health of biological resources and to further develop predictive capabilities of the interactive processes that regulate and influence biodiversity and ecosystem integrity. These processes include the functioning of biological systems and their relationship and interdependence to physical, chemical, geological and hydrologic factors and their response to human and natural environmental stresses through research focused on species, population, and ecosystem research. DOI also communicates the results of inventory, monitoring, research, technology, and methods development through development of an information infrastructure to support exchange, integration, and application of biological data to biodiversity and ecosystem conservation issues.

DOI global change research aims to improve understanding of the processes associated with terrestrial-oceanic and terrestrial-atmospheric exchanges of water, energy, carbon, and nutrients; to describe, analyze, and monitor past and contemporary states, changes, and processes in the earth's physical, biological, geological, chemical, and ecological systems; facilitate access to and use of global change information for policy decisions, resource management, research, and education; and to develop the ability to predict the effects of global change on public lands and natural resources.

DOI programs include studies of the status and trends of the nation's surface and groundwater resources and analysis of natural and human factors affecting the quality of those resources; research on improved water treatment technology; studies of the availability and use of water resources throughout the nation, including regulated aquatic ecosystems; investigations of toxic substances needed to improve waste disposal practices and cleanup; studies of geologic and oceanographic processes affecting the health of coastal and marine environments including coastal wetlands change and transport and accumulation of contaminated sediments; and integrated investigations of critical processes in stressed aquatic ecosystems.

To provide information needed to reduce natural disasters, basic research is conducted on geologic (earthquakes, volcanoes, and landslides) and hydrologic (floods, droughts, subsidence, and dam safety) hazards. DOI research also provides hazard and risk assessments on national, international, regional, urban, and local scales and develops monitoring networks and geographic information systems. The department is also responsible for transferring technology needed to enhance professional skills and expand technical capacity for mitigation, preparedness, emergency response, and recovery and the organization and conduct of postdisaster investigations.

DOI conducts geological, mineral, and energy resource assessments and environmental investigations and studies of the ecological, economic, and social factors involved in the development and management of offshore oil, gas, and mineral resources. DOI research includes development of new mineral recovery concepts that will safeguard workers and prevent environmental harm and research to conserve resources through recycling and preventing environmental problems or damage to the infrastructure. Inventory, monitoring, and conservation of living resources and their ecosystems, as well as research toward their sustainable development, are high-priority programs.

In the toxic substances and hazardous and solid waste area, DOI conducts research primarily directed toward improvements of waste-disposal and cleanup practices and the mitigation of contamination problems by addressing major types of contamination and developing new methods to reduce the volume and toxicity of processing wastes from mining and mineral operations and assessing the impact of contamination on fish, wildlife, and the environment. DOI also conducts research to understand the fate, transport, and effects of contaminants through ecosystems and the role of biological processes in the control and mediation of chemical speciation and to develop risk-based action levels of contaminants.

DOI air quality research includes the collection of data and information on air quality conditions and trends in national parks and wilderness areas, effects of air pollution on resources, the pollutants responsible for resource damage, sources of pollutants, and the effect of reducing emissions at these sources. Present monitoring and research programs are focused on acid deposition, ozone, and fine particles as they affect visibility including understanding and predicting the transport and chemical transformation of air pollutants.

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U.S. Department of Transportation (DOT)

DOT environmental R&D focuses on environmental programs that relate to transportation issues. As such, DOT resources contribute to both the CENR and the NSTC Committee on Transportation.

Contribution to the CENR Interagency R&D

The DOT will examine the effects of reductions of carbon monoxide, nitrogen oxides, hydrocarbons, and other greenhouse gas emissions from the production and use of personal motor vehicles. Preliminary plans include development of coordinated and mutually consistent data bases on impacts, an assessment of alternative transportation system impacts on human health and ecosystems, and an impact assessment of transportation and trans-shipment requirements in urban and rural settings.

Other DOT environmental research falls primarily in the areas of socioeconomic dimensions of environmental change and environmental technologies. This includes determining ways it can support the Partnership for a New Generation of Vehicles. This project will develop critical information, data bases, and the analytic tools necessary to integrate mobility and environmental needs in a new generation of vehicles. This will include peer review of analyses and research plans and developing a comprehensive behavioral, economic, social science, and technology data base to support policy formulation.

U.S. Environmental Protection Agency (EPA)

To fulfill its statutory mandates, the EPA is involved in a broad range of environmental science and policy issues. The EPA's R&D program provides the scientific and technical basis for the agency's decision making and complements the more fundamental research supported by agencies such as the NIEHS and the National Science Foundation (NSF).

The EPA develops improved risk assessment methodologies for both human health and ecological systems and the complex data needed to reduce scientific uncertainties for decisions. The human health research program focuses on developing the biological methods, models, and data needed to improve the EPA's ability to estimate health risks. Human exposure assessment research includes exposure measurement and monitoring programs, predictive models to characterize exposures to pollutants, and improved methods for data collection. The EPA has developed and manages the Integrated Risk Information System, an on-line data base used worldwide for human health risk assessment information.

The focus of the EPA's ecological risk assessment program is to reduce uncertainty at the watershed, regional, and national scales through monitoring, modeling, and assessment activities. The EPA is a major contributor to federal research on ecosystem protection, which is critical to effective government-wide policies on ecosystem management. For example, EPA research supports place-based ecosystem protection approaches for more effective management of ecosystems in the Pacific Northwest, the Great Lakes, and south Florida. The EPA is developing methodologies for ecological risk assessment and through the Environmental Monitoring and Assessment Program is focusing its research to help develop ecological indicators of resource condition.

The EPA conducts a multimedia R&D program in risk management that both supports specific regulatory activities and leads to more cost-effective, innovative approaches to obtaining environmental improvement. This research addresses the full range of prevention, monitoring, control, and remediation technologies and approaches. The research spectrum is from fundamental research to field demonstration and evaluation. The research is intended to facilitate user-friendly dissemination of data and information to state and local governments and other industrial and community groups. Partnerships with industry, academia, and other agencies are an integral part of these R&D programs.

The EPA is currently restructuring its research programs to improve the quality of science and ensure that the focus is on environmental issues with the highest risk. One change is a significant increase in funding of extramural investigator-initiated grants to better incorporate the substantial expertise of the academic community. The grants will include a joint EPA-NSF effort that targets watershed ecosystems, pollution prevention, and socioeconomic issues, as well as an EPA effort that targets risk assessment methodology, global climate change, and air pollution. All EPA research will be supported by the extensive use of peer review for project selection and for results quality. The EPA is also greatly expanding its academic fellowship program to increase government support for academic training in environmental sciences. Under the restructured research program, the EPA will strive for an equal mix of short-term and long-term research to achieve a balanced program of support for agency activities that both meets immediate needs and keeps EPA at the cutting edge of science.

Federal Emergency Management Agency (FEMA)

Resources for FEMA programs relating to environment and natural resources are not included in CENR-focused R&D but nevertheless are critical to the Natural Disaster Reduction issues addressed by the CENR.

Contribution to the CENR Interagency R&D

Specific FEMA programs contributing to the CENR include: (1) the Steel Buildings Project: developing guidelines for repair and retrofit of buildings damaged by the Northridge earthquake; (2) seismic rehabilitation of existing buildings, which develops building practices that increase their ability to withstand earthquakes and provides technical material on identifying buildings that might be hazardous in an earthquake, methods for identifying structural flaws, an a compendium of commonly used techniques for seismic rehabilitation, and; (3) the National Earthquake Hazard Reduction Research Program, which develops, updates, and maintains criteria for design and construction of buildings subject to earthquakes.

National Aeronautics and Space Administration (NASA)

NASA brings to environment and natural resources research the ability to view the earth in its entirety from space. This vantage point has led NASA to focus on the study of the earth as a integrated system, examining physical climate systems, biogeochemical cycles, and the linkages between the two.

Contribution to the CENR Interagency R&D

Mission to Planet Earth (MTPE), one of NASA's five strategic enterprises, is the agency's contribution to environment and natural resources research. MTPE employs spacecraft, aircraft, balloons, and selected ground-based observations, often in tandem, to collect data useful in a broad range of regional-to-global scale inquiries. These global-scale investigations are conducted in close collaboration with science and space agencies in Japan, France, Germany, Italy, Great Britain, Brazil, Russia, Australia, and Canada, as well as with international organizations such as the European Space Agency and the United Nations Environment Program. MTPE research activities are monitoring the pattern of stratospheric ozone concentration changes and have mapped the falls and rises of these concentrations centered over the Antarctic continent. Analyses of these results have demonstrated the linkages between human-made CFCs and ozone depletion, further validating the policy decisions made by the many nations committing themselves to the Montreal Protocol on Substances that Deplete the Ozone Layer.

MTPE has produced the first global map of ocean circulation using a space-based radar altimeter. This information is crucial to the study of the periodic El Nino-southern oscillation events that affect precipitation and agriculture in the United States and many other nations. Using data from a space shuttle-based multiple frequency/multiple polarization synthetic aperture radar, MTPE has produced images of geologic features under the sands of the Sahara, population-threatening mudflows around the Mt. Pinatubo volcano, and the lateral extent of flooding below the thick jungle canopy of Manaus, Brazil. MTPE has conducted research on the use of Global Positioning System arrays around the Los Angeles basin to detect ground shifts and "map" fault lines. Using a space-based thematic mapper instrument, MTPE has enabled the generation of a long-term global archive of land cover change that has found an enormous variety of applications of both commercial and scientific value. These data have been used to resolve a long-standing debate on the true rate of deforestation in the Amazon rainforest.

These and other data collection and scientific analysis efforts are enabling researchers to continue to fill in a conceptual model of the earth system with real understanding. In the coming few years, MTPE will be working to provide the data and analysis required to unlock the carbon cycle, resolve current questions in stratospheric chemistry, and develop the first integrated model of the global atmosphere, oceans, and land surface. Observations of global atmospheric ozone will continue, and new missions will investigate tropical rainfall patterns and ocean surface winds, which are crucial elements in understanding the earth system. An ambitious program of earth observation from multiple space platforms will provide a 15-year or longer data set of a wide range of parameters beginning in 1998, enabling a systematic investigation of global climate change. MTPE makes possible the study of regional-to-global scale changes and associated impacts on the environment and natural resources.

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National Science Foundation

As an agency whose mission is support of fundamental research across the entire range of science and engineering disciplines, the NSF has supported a diverse set of research activities dealing with topics covered by all CENR subcommittees.

Contribution to the CENR Interagency R&D

NSF's global change research emphasizes the support of activities that advance fundamental understandings of the complex interactions among different facets of the earth system. In addition to expanding knowledge of physical, biological, and socioeconomic processes, NSF seeks to facilitate data-acquisition and data-management activities necessary for basic research on global change, advancement of modeling activities, and advancement of methods for conducting integrating assessments and on research that examines the processes used by governments and other organizations to identify and evaluate different types of policies for mitigation, adaptation, and other responses to changing global environmental conditions.

NSF addresses biodiversity and ecosystem function through support of biological surveys and inventories, research on the functional role of species in ecosystem processes and sustainability, long-term research on trends in natural resources, and international comparisons and scientific collaborations. Research is supported that improves knowledge about approaches for the management, conservation, and use of natural resources in ways that sustain or enhance terrestrial and marine ecosystems and the quality of life.

Research on air quality increases understandings of the causes of degraded air quality and provides information needed to improve remediation. Research includes studies of the chemical and physical processes that control tropospheric ozone concentrations over North America and the northern Atlantic Ocean. These activities will be coordinated with the North American Research Strategy for Tropospheric Ozone organization and include observational studies of tropospheric ozone and its chemical precursors, laboratory investigations of associated chemical kinetics and mechanisms, development of improved analytical instrumentation and sampling strategies, and construction and evaluation of relevant models.

NSF research related to toxic substances and solid and hazardous wastes focuses on development of technologies for pollution avoidance through minimization of the use and release of toxic substances. Among the lines of research supported are environmentally benign methodologies for the synthesis of chemicals and materials, the design and manufacture of materials that are durable yet degradable, and computational approaches to predicting the fate and persistence of chemicals in the environment.

Research on environmental technology includes studies of environmentally conscious design and manufacturing systems, remediation and restoration techniques and new environmental technologies; and new monitoring and assessment methods for the measurement and characterization of environmental problems and the analysis of better methods for technological responses.

Water resources research includes disciplinary and interdisciplinary research on topics such as hydrology, aquatic ecology, oceanography, and civil engineering that is often linked to questions that involve social and economic sciences, international dimensions, geochemistry, polar sciences, and other fields. Special emphasis is being placed on advancement of interdisciplinary science and engineering that takes a systems approach to questions involving water and watersheds.

Natural hazard studies improve understanding of the physical processes that underlie atmospheric, hydrologic, seismic, soil, and ground movement hazards; improved hazard prediction and forecasting methodologies; new and improved warning, evacuation, and response systems; new methods to assess risk, damage, and cost-mitigation methods; and enhanced understandings of recovery and reconstruction processes.

NSF supports fundamental research in social and economic sciences on the interaction between human and natural systems, with an emphasis on the social and behavioral processes that shape and influence those interactions. Examples of NSF-sponsored research include anticipatory and reactive adaptation and mitigation, resource use and management, global collective action, international trade patterns and global sectoral models, and the impact of the population on the environment. Special emphasis is being placed on research examining the role of institutions, cultural norms, values, and human actions on the formation, implementation, and evaluation of environmental policies.

Risk analysis, societal and public policy decision making, behavioral decision making and judgment, and decision making under uncertainty are supported with special emphases on judgment and decision processes; risk perception, communication, and assessment; and modeling of responses to risk.

Smithsonian Institution (SI)

The SI is an independent trust instrument of the United States that fosters the increase and diffusion of knowledge. The SI performs fundamental research and engages in national and international cooperative research.

Contribution to the CENR Interagency R&D

To monitor and understand indicators of natural and anthropogenic environmental change on daily and decadal time scales, including solar radiation, atmospheric composition, sea-level fluctuations, and desertification, monitoring programs are conducted by the Smithsonian Astrophysical Observatory, the National Air and Space Museum, and the Smithsonian Environmental Research Center. Long-term indicators of environmental change are studied at the National Museum of Natural History (NMNH) to understand the natural processes and rates of ecological oceanographic and volcanic phenomena as they effect the global environment.

Research is conducted at the Smithsonian Tropical Research Institute (STRI) on ecosystem responses to climate change. Studies and tropical biological diversity are carried out at NMNH and STRI to inventory and document species distribution in tropical forests, monitor changes, and identify physical and biological processes of growth and decline. Research is conducted to understand the response of species fragmentation and to understand and ensure the maintenance of the productivity of tropical coastal ecosystems.

Studies are also conducted on human interactions with changing ecosystems, focusing on the long history of human modification of ecosystems and human responses to changing environments.

Tennessee Valley Authority (TVA)

TVA is responsible for planning for the proper use, conservation, and development of the natural resources of the Tennessee River drainage basin and its adjoining territory for the general social and economic welfare of the nation. Its business today incorporates a broad mix of regional and national responsibilities, including power generation, navigation, flood control, shoreline management, recreation, environmental research, and economic development.

Contribution to the CENR Interagency R&D

TVA's environmental R&D is centralized at the Environmental Research Center in Mussel Shoals, Alabama. The center develops information and innovative technologies to help identify and remediate air and water pollution and ground contamination. Data from research programs are transferred to regulatory agencies, policymakers, special interest constituencies, industries, and resource managers through national and international leadership and scientific networks. The center is focused on developing technologies to address three critical environmental concerns: regional tropospheric ozone non-attainment; agricultural pollution in surface and groundwater; and PCB, styrene, and wastewater contamination from industrial processes.

Research is conducted on ground-level ozone, acid rain, air toxics, and climate change, including emission control strategies, characterizing ozone impacts on natural forest stands, and predicting forest response to ozone under varying conditions.

Technical assistance is provided on pollution prevention for agrichemical industries, including converting poultry litter into useful products, intercepting pollutants in surface water runoff to improve water quality and to protect shorelines through innovative techniques, characterizing and modeling watersheds for better decision making, and introducing alternatives to agrichemicals for controlling aquatic plants.

TVA biotechnology research develops and demonstrates new technologies for PCB remediation of contaminated areas, provides low-cost biofilter technology to private industry for removing air pollutants, works with private industries and other agencies to scale-up biomass conversion technology for ethanol and chemical production, develops low-cost environmental sensors to detect and measure chemicals for remediation and industrial process monitoring contaminants, and develops and demonstrates constructed wetlands for cleanup of wastewaters.

Appendix C

List of Acronyms

Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
CAAA	Clean Air Act Amendments
CDC	Centers for Disease Control
CENR	Committee on Environment and Natural Resources
CFC	chlorofluorocarbon
DDT	dichlorodiphenyltrichloroethane
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
EOS	Earth Observing System
EPA	U.S. Environmental Protection Agency
FEMA	U.S. Federal Emergency Management Agency
GCOS	Global Climate Observing System
GOOS	Global Ocean Observing System
GTOS	Global Terrestrial Observing System
HAP	hazardous air pollutant
HHS	U.S. Department of Health and Human Services
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
MTPE	Mission to Planet Earth
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program
NARSTO	North American Research Strategy for Tropospheric Ozone
NASA	National Aeronautics and Space Administration
NBS	National Biological Service
NCEH	National Center for Environmental Health
NCI	National Cancer Institute
NEI	National Eye Institute
NIAMS	National Institute of Arthritis and Musculoskeletal and Skin Diseases

NIEHS	National Institute of Environmental Health Sciences
NII	National Information Infrastructure
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
NMNH	National Museum of Natural History
NOAA	National Oceanic and Atmospheric Administration
NO_x	nitrogen oxides
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSTP	Office of Science and Technology Policy
PCB	polychlorinated biphenyl
PM	particulate matter
R&D	research and development
SI	Smithsonian Institution
STRI	Smithsonian Tropical Research Institute
TVA	Tennessee Valley Authority
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USDA	U.S. Department of Agriculture
UV	ultraviolet
WCRP	World Climate Research Program
WMO	World Meteorological Organization

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